INFLUENCE OF CONSTRUCTION CHARACTERISTICS AND HOME MAINTENANCE PRACTICES ON SUBTERRANEAN TERMITE INFESTATION RATES IN NORTHEASTERN FLORIDA

By

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Abstract of Dissertation Presented to the Graduate School
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INFLUENCE OF CONSTRUCTION CHARACTERISTICS AND HOME MAINTENANCE PRACTICES ON SUBTERRANEAN TERMITE INFESTATION RATES IN NORTHEASTERN FLORIDA

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This research determined the effects of construction practices and home maintenance on subterranean termite infestations in two phases. The first phase investigated the effect of cement contamination on residual performance of termiticides in the laboratory. The second phase examined the influence of home building and maintenance practices on infestation rates of houses in three northeastern Florida counties.

First, a laboratory bioassay with *Reticulitermes flavipes* (Kollar) was conducted 5 days after soil was mixed with portland cement to alter pH levels to 6, 7, 8, and 9. Termites were confined to soil treated with 10x, 1x, 0.1x, or 0.01x the manufacturer's suggested application rates for imidacloprid, fipronil, chlorpyrifos, bifenthrin, permethrin, or cypermethrin. Results of additional bioassays at 5 and 10 months indicated that alkaline soil pH significantly decreased residual efficacy of imidacloprid and fipronil at

0.1x label rates, and chlorpyrifos, bifenthrin, and permethrin at 0.01x the label rates. Cypermethrin was not affected by soil pH.

Second, homeowner responses to a mailed survey allowed classification of single–family houses built between 1994 and 1998 in Jacksonville Beach, St. Johns County, and Flagler County according to their subterranean termite infestation history, construction type, and maintenance characteristics. Pest control companies and county records provided preconstruction soil chemical treatment information. Infestation rates were 17.60% from Jacksonville Beach, 15.85% from St. Johns County, and 2.70% from Flagler County. Subterranean termite infestations were strongly associated with older houses with wood frames. Conditional logistic regression of covariates showed relationships among factors known to be conducive to subterranean termite infestations in order of their influence on infestation likelihood were political boundary > occurrence of structural wood > repellent preconstruction termiticide treatment > termite access to structure via foraging guidelines and lack of foundation perimeter inspection space.

I also evaluated the effect of the St. Johns County Building Code on infestation rates of houses built after addition of a Termite Protection Ordinance. The 1996 Ordinance was enacted in order to decrease subterranean termite infestation rates. Poor implementation of the Ordinance made it impossible to fully evaluate its impact.

CHAPTER 1
INTRODUCTION

Termites decompose organic matter (Collins 1989, Donovan et al. 2001) and help maintain nitrogen and carbon cycles (Waller et al. 1989, Tayasu et al. 1997), and are thought to be a key contributor to soil heterogeneity (Donovan et al. 2001). Their diversity is influenced by habitat, with the highest number of species found in wet lowland tropical forests (Eggleton 2000). Southern latitudes have more termite species and endemism than their northern counterparts (Eggleton 1994). Eggleton (2000) hypothesized that this trend is due to protection of southern regions from the effects of glaciation. He also suggested that Isoptera originated in the Cretaceous Period (Mesozoic Era, ~144 mya) on Pangea, and that the subsequent evolution of groups was due to continental separations (Eggleton 2000).

Within North America, the most speciose regions are Florida, northern Mexico and the southwestern United States (Weesner 1965). Termites inhabiting these areas include genera derived from Central and South Americas. According to Thorne et al. (1993), the only North American endemic is *Zootermopsis* Emerson. However, *Reticulitermes* has the widest overall distribution in the region (Weesner 1965).

Within the United States, the genus *Reticulitermes* includes six species of economic impact (Su and Scheffrahn 1990a). *Reticulitermes arenincola* Goellner can be found from the Midwestern through the Northeastern U.S. and is considered to be of small economic impact compared to other species (Edwards and Mill 1986).

Reticulitermes hesperus Banks represents the major termite pest in the western United States (Kofoid 1934, Snyder 1954, Weesner 1965, Edwards and Mill 1986). *Reticulitermes tibialis* Banks and *R. hageni* Banks, both found in the midwestern through eastern United States, are also known to cause structural damage but are reported less frequently (Kofoid 1934, Edwards and Mill 1986, Su and Scheffrahn 1990a). Both *R. flavipes* (Kollar) and *R. virginicus* Banks are found in most of the U.S., except the northwestern states (Su and Scheffrahn 1990a).

Reticulitermes flavipes is probably the most economically important termite in the southeastern states (Su and Scheffrahn 1990a). The economic impact of *R. virginicus*, however, is unknown. *Reticulitermes virginicus* infestations were misidentified as those of *R. flavipes* because of morphological similarities between the two species (Su and Scheffrahn 1990a). In cooperation with pest management professionals, data are being collected to verify the economic impact of *R. virginicus.* Reports of *R. virginicus* infestations are increasing in number, especially in Florida (Su and Scheffrahn 1990a), suggesting *R. virginicus* may be as significant a pest as *R. flavipes.*

Biology of *R. flavipes and R. virginicus*

The new *Reticulitermes* colony is founded by the royal pair after their nuptial flight, in which the fertile primary reproductives (alates) leave their colony seeking to establish new colonies. In Florida, the eastern subterranean termite (*R. flavipes*) swarms January to April, while the dark southern subterranean termite *(R. virginicus)* swarms March to May (Scheffrahn and Su 1994). They both swarm during midday in sunshine, and may also swarm during fall months (Scheffrahn and Su 1994).

The number of individuals within the termite colony varies (Thorne et al. 1997). Under laboratory conditions and without the intrusion of periodic sampling by researchers, the mean size of 2-year old *R. flavipes* colonies bred from royal pairs was 387 ± 226 and ranged from 51 to 984 individuals, excluding eggs (Thorne et al. 1997). Direct excavation of colonies has led to population estimates of 51,505 to 363,512 (Howard et al. 1982). Using mark-release-recapture techniques total *Reticulitermes* colony populations have been estimated at 25,000 to 5 million (Esenther 1980a, Grace et al. 1989, Grace 1990, Su et al. 1993a).

Primary *Reticulitermes* reproductives are rarely found in the field, and fecundity of the founding female decreases over time (Thorne et al. 1999). Brachypterous and apterous neotenic (second and third forms, respectively) reproductives are more frequently encountered than primary reproductives in the field (Snyder 1954). Both supplemental types contribute to the total egg production within the colony (Pickens 1934, Snyder 1954, Buchli 1958, Pawson and Gold 1996, Thorne 1996). Neotenic reproductives (also referred to as "supplemental reproductives") can differentiate within their colony while the royal pair is still alive and reproducing (Snyder 1920, Noirot 1989). Individual female neotenic reproductives are less fecund than alate-derived queens (Snyder 1920). However, hundreds of these supplemental reproductives may occur within the colony, so their cumulative egg contribution can exceed that of the primary queen (Howard and Haverty 1980, Myles and Nutting 1988, Thorne 1996).

Reticulitermes colony formation may also occur through budding, although budding does not always produce new colonies (Thorne et al. 1999). Thorne (1999) defined budding as occurring when satellite colony units form as aggregates of nestmate

groups that spend time separated from the primary reproductives. Supplemental reproductives may differentiate within the new units (Thorne 1999). Budding has been reported in both *R. flavipes* and *R. virginicus* to occur either actively, when a critical mass is reached (Snyder 1948); or passively, due to some physical separation (Pawson and Gold 1996). When small groups of *Reticulitermes* nymphs were isolated from their royal pairs, brachypterous and apterous neotenic reproductives formed within 4 (Pawson and Gold 1996) and 10 months (Pickens 1934), respectively. Pawson and Gold (1996) reported that *R. flavipes* and *R. virginicus* supplemental reproductives produced viable progeny (eggs and nymphs) within 5 and 7 months, respectively.

Colonies of *Reticulitermes* have no permanent, central nest site. Thorne et al. (1999) described them as "mobile and amoeboid rather than sessile." Snyder (1936) hypothesized that the entire colony may relocate or bud in response to temperature, moisture, resource conditions, season, or stage of colony growth.

Reticulitermes and all other termites are considered to be eusocial. They have overlapping generations within their colonies, colony members cooperatively care for brood, and they have a division of labor that allows members to individually contribute to a productive, adaptable society. Their division of labor constitutes a social structure consisting of three castes: reproductives (discussed above), workers, and soldiers. Workers feed the other castes, forage for resources, and participate in colony defense. Soldiers are a defensive caste and comprise about 1-2% of *R. flavipes* (Howard and Haverty 1980, Thorne et al. 1997) and *R. virginicus* (Pawson and Gold 1996) colonies.

Reticulitermes flavipes and *R. virginicus* Feeding and Tunneling

Subterranean termites build underground tunnel networks which provide them protection from predation and dessication while foraging. Tunnel construction is influenced by the number of tunnels present, physical barriers, direction, and soil moisture. Subterranean termites tended to tunnel in directions that evenly divide their search area (Robson et al. 1995, Powell 2000, Campora and Grace 2001, Puche and Su 2001). They readily used pre-formed tunnels. Kirton et al. (1998) observed subterranean termites using tunnels in corrugated cardboard. Pitts-Singer and Forschler (2000) speculated termites would readily use tunnels made by other colonies or those formed by decomposed roots or earthworms. Tests with wires placed in soil-filled arenas resulted in *R. flavipes* following 47% of the encountered wires and *R. virginicus* following 42% (Pitts-Singer and Forschler 2000). *Reticulitermes* prefer to construct tunnels directed downward or horizontal versus upward (Pitts-Singer and Forschler 2000). In laboratory tests, *R. flavipes* tunneled faster in sand and clay with moderate moisture (by weight) of 10 to 25% or 20 to 30%, respectively, compared to soils with lower or higher moisture content (Gahlhoff 1999). While some research indicates wood volatiles act as kairomones (chemical emitted by one species and perceived by another species which benefits; Gordh and Headrick 2001) that guide subterranean termites to food placed in loose substrates or open-air settings (Clement et al. 1988, Reinhard et al. 1997), Puche and Su (2001) found no indication that *R. flavipes* workers were able to detect wood in sand over distance.

Consumption of a substrate by a subterranean termite colony is affected by colony population density (Esenther 1980b, Lenz and Barrett 1984), vigor (Su and LaFage 1984, Lenz 1985), substrate composition (Smythe and Carter 1969, Behr et al. 1972, Carter and

Dell 1981, Carter and Huffman 1982, Duryea et al. 1999), previous damage to substrate by conspecifics (Delaplane and La Fage 1989b), temperature (Haverty and Nutting 1974), and moisture (Delaplane and La Fage 1989a). Although *Reticulitermes* have been shown to prefer rotted wood over sound wood (Schultze-Dewitz 1972, Amburgey 1979, Waller et al. 1987), there is some uncertainty regarding termite preference for certain fungal species, such as the white-rot genus, *Ganoderma* (Amburgey and Beal 1977, Waller et al. 1987).

Amount of wood consumed by individual termites is affected by placement and type (Oi et al. 1996), volume (Waller and LaFage 1987, Hedlund and Henderson 1999, Wang and Powell 2001), and size (Gentry and Whitford 1982, Waller 1988, Wang and Powell 2001). Consumption incidence and quantity by individual termites is unpredictable (Forschler 1996).

Researchers have assessed the minimum distance traveled by tunneling and foraging termites with mark-release-recapture and mapping studies. Workers from a single *R. flavipes* colony explored resources over a linear distance of up to 79 m and over an area of up to 2,361 m^2 (Oi 1994, Grace et al. 1989, Grace 1990, Su et al. 1993a). Although habitat (undeveloped vs. residential) was not correlated with colony population size (Su et al. 1993a), population size and territory seem to differ among *Reticulitermes* found in different geographic locations. For instance, foraging populations and territories from South Florida (Su et al.1993a) were larger than those described in Gainesville, Florida (Oi 1994).

The Evolution of Subterranean Termite-Resistant Construction

Essentially, subterranean termite control is the process of preventing termites from feeding on any cellulose-containing material in a structure. Understanding the relationship between subterranean termite biology and construction and landscaping practices is relevant to prevention and control efforts.

Wood Preservatives With Emphasis on Borate Treatments

One of the earliest records of preventative subterranean termite control dates back to 1756 when creosote was first reported as a wood preservative (Rambo 1997). It became widely used in 1865 when a pressure-treatment plant was built in Massachusetts. However, creosote use decreased because it is explosive, causes skin and eye irritation, smells bad, and resists paint. Commercial wood preservatives used after creosote use ended included Bruce preservative (naphthol), sodium fluoride based Wolman salts, zinc meta-arsenite (including chromated copper arsenate), pentachlorophenol, copper naphthenates, cuprinol products, and borates (Rambo 1997). With the exception of borates, these wood preservatives are no longer used for interior wood because of environmental and human health concerns .

Borate wood preservatives protect wood from decay fungi and wood-destroying insects (Williams and Amburgey 1987, Williams et al. 1990, Su and Scheffrahn 1991). Borate treatments are currently applied to structures for preventive and remedial control of termites. Toxicity to termites is probably due to interference with the digestive process (Williams et al. 1990). Subterranean termites feeding on wood containing 100 ppm boron died within 2-4 weeks (Jones 1991, Grace 1992, Williams 1997). However, >2,500 ppm boric acid equivalent was needed to deter both *C. formosanus* and *R. flavipes* from

feeding on wood treated with sprayed on Bora-Care (Nissus Corp.; Su and Scheffrahn 1991).

Surface-applied borates in wood exhibit moisture-dependent mobility after the first week of treatment (Schoeman et al. 1998). Significant wood diffusion was noted one week post-treatment of DOT in wood having a moisture content >15%. Moisture content of the wood was more important than wood species (Schoeman et al. 1998). With a moisture level of <10%, borates will be deposited 3-10 mm into wood (Williams 1997). DOT sprayed on the surface of southern yellow pine or Douglas fir having moisture content of 10-15% will penetrate 6-12 mm into the wood (NPCA 1992).

Borate solutions are prepared in monoethylene glycol or water, to facilitate diffusion of sprayed-on borate products through dry wood (Becker 1976). (This treatment allows thorough penetration into new structural lumber, which has a normal moisture content of 16-18% (Levi 1986)). For remedial control, subterranean termites may enhance the diffusion rates of borate products in infested wood, since they transfer water to their feeding sites (Grube and Rudolph 1999). Bora-care spray-on treatments protected pine (*Pinus* spp.) from both *C. formosanus* and *R. flavipes* when wood contained > 2,500 ppm boric acid equivalent (Su and Scheffrahn 1991). Pine and spruce are both commonly used in Florida construction (pers. comm., H. T. White, Deputy Chief Building Inspector, St. Johns County, Florida).

Unpalatable Wood

Subterranean termites have shown preferences for certain wood species over others in laboratory tests (Smythe and Carter 1969, 1970, Behr et al. 1972, Mannesmann 1972, Carter and Smythe 1974, Esenther 1977, Carter 1979,Carter and Dell 1981). For

example, both *R. flavipes* and *R. virginicus* prefer pine species over melaleuca (Duryea et al. 1999) and cypress (Smythe and Carter 1969, Carter and Huffman 1982). In general, decayed and/or moist wood is preferred over sound, dry wood (Smythe et al. 1971, Schultze-Dewitz 1972, Amburgey 1979, Waller et al. 1987, Delaplane and LaFage 1989a) and softwood is preferred over hardwood (Behr et al. 1972).

Soil Treatments

In the 1920s and early 30s, soil treatments were used frequently in southern California as remedial treatments for subterranean termite infestations. The most common treatment was a 10% sodium arsenite solution applied to the ground or in a trench dug under or around infested houses at the rate of 1 gal per 100 ft^2 (Randall and Doody 1934). Although laboratory studies showed topically applied sodium arsenite was toxic to subterranean termites, soil treatments had high failure rates (Randall and Doody 1934). In response to these failures, 2 to 6% solutions applied at 10 to 50 gal per 100 ft^2 were evaluated. Control recommendations then changed to using large amounts of dilute solutions to obtain a thicker layer of treated soil around structures (Randall and Doody 1934). The posting a conspicuous permanent warning sign stating the ground had been poisoned by sodium arsenite was also recommended (Randall and Doody 1934). One report strongly cautioned against the use of any arsenical soil treatments due to their high toxicity (Randall and Doody 1934).

The 1940s saw the emergence of soil termiticides such as the chlorinated hydrocarbon DDT (dichloro-diphenyl-trichloroethane) and the cyclodienes chlordane, aldrin, heptachlor, and dieldrin. DDT at 2% in sandy loam persisted at least 33 years, killing 61% of the *C. formosanus* in bioassays with 24-year old soil (Grace et al. 1993).

Cyclodienes persisted over 35 years (Kard et al. 1989). Dieldrin in sandy loam at 0.30% killed 99% of the *C. formosanus*, even after the soil had been exposed to the environment for 33 years (Grace et al. 1993). While persistence was a desirable trait, it caused environmental concern and eventually led to the withdrawal of all cyclodiene termiticides from the U.S. market by 1988.

Less persistent termiticides, such as chlorpyrifos and the pyrethroids, are currently used by pest management professionals. Chlorpyrifos and the pyrethroids cypermethrin, permethrin, and fenvalerate were 100% effective against subterranean termites for 9 and 6 years, respectively, in Florida soil (Kard 2001). Chlorpyrifos use is currently being phased out due to the concerns arising from the Food Quality Protection Act of 1996. Pyrethroids repel termites from treated areas without causing significant mortality (Su et al. 1993b). The newer, slow-acting toxicants are nonrepellent and include imidacloprid (Kuriachan and Gold 1998) and fipronil (Osbrink et al. 2001). In field tests, both have provided at least 5 years of 100% protection of wood within concrete slabs on Florida soil (Kard 2000).

Soil termiticides protect structures by either repelling or killing termites that enter the treated area. In studies with *C. formosanus*, Su et al. (1982) defined three types of termiticides: type I was instantly repellent, type II was slowly repellent, and type III was nonrepellent. All currently available pyrethroids are considered to be type I termiticides (Su et al. 1982, Su et al. 1995). At termiticidal application rates, type I termiticide treatments will result in low mortality due to their repellent effect.

Chlorpyrifos is acutely toxic to subterranean termites and was grouped with the type II termiticides (Su et al. 1982). Su et al. (1982) observed termites entering the

chlorpyrifos-treated area for the first few days. They reported that avoidance of the treatment did not occur until "there were many dead and decaying individuals in the treated area," and speculated that secondary repellency occurred due to the decomposing bodies of dead termites within the treated area (Su et al. 1982, Su and Scheffrahn 1990b). At termicidal application rates, type II termiticide treatments will result in initial mortality of individuals entering the treated area, and subsequent low mortality when termites begin to avoid the treatment.

Imidacloprid, fipronil, and chlorfenapyr are considered to be slower-acting than both pyrethroids and chlorpyrifos and are nonrepellent (Kuriachan and Gold 1998, Osbrink et al. 2001, Wagner et al. 2003). At termiticidal application rates, these soil treatments should result in high mortality of exposed individuals away from the treated area. Slow-acting imidacloprid prompted the USDA-Forest Service to make the first protocol change. Before imidacloprid field tests, wood plots either passed or failed according to whether or not damage was noted. Imidacloprid soil treatments resulted in delayed mortality of termites, which allowed them to cause some surface etching of wood before death. Once the delayed effect of imidacloprid was detected, plots no longer strictly either passed or failed. Instead, wood in plots were rated on a scale similar to that of the American Society for Testing Materials (ASTM), which allowed for acceptable surface etching (Wagner et al. 2003). A second protocol change occurred after some field experience with fipronil soil treatments caused suspicion of the treatment being spread from termite to termite. Before fipronil, control plots were placed near treatment plots in tests. Due to lack of activity in control plots after 3 to 5 years, fipronil tests were redone with control and treatment plots separated (Kard 2001).

Population Control With Baits

Currently registered baits contain either hexaflumuron, diflubenzuron, or sulfluramid. The most extensively studied active ingredient, hexaflumuron, has been reported to eliminate subterranean termite activity at several locations with several species (Su 1994, Su and Scheffrahn 1996, Peters and Fitzgerald 1999, Sajap et al. 2000, Rojas and Morales-Ramos 2001, Grace and Su 2001). Researchers found no differences in *C. formosanus* consumption rates of bait matrices containing 250 ppm diflubenzuron, hexaflumuron, or chlorfluazuron, and all laboratory colonies died within 9 weeks (Rojas and Ramos 2001). Foraging populations of *C. formosanus* were reduced 65 to 98% within one year by baits containing 600 ppm sulfluramid (Su et al. 1991a).

Principles of Termite Prevention

Soil treatments were first used for remedial rather than preventive measures. Prevention recommendations were later developed and consisted of three basic principles: 1) structures should be inaccessible to termites, 2) structural wood should be unpalatable to termites, and 3) termite foraging in the vicinity of the structure should be discouraged (Brown et al. 1934). These principles are part of the National Pest Control Association's (NPCA) Approved Reference Procedures for Subterranean Termite Control, the St. Johns County Termite Protection Ordinance, and the current Florida Building Code (FBC) (NPCA 1980, SBCCI 1994 and 1997, FBC 2002).

The NPCA identified 50 basic elements of construction which must be considered in termite control in their Approved Reference Procedures for Subterranean Termite Control (1980). These included areas where termites could enter a structure unseen through cracks, such as brick veneer below grade on a frame house or through a concrete

foundation. NPCA (1980) also identified construction elements in which wood is in close proximity to the ground, such as supported slabs of basementless wood frame houses and earth filled wooden porches, among their list of construction elements. For each of the 50 cases, the NPCA identified the condition that allowed for subterranean termite infestation and the difficulty in treating the area. For example, for floating or supported slab floor construction of wood frame houses, termites may gain access through the block voids of the foundation, through the space between the slab and a block, or through a space between the slab and exterior cladding. NPCA warned of the hazard in treating this type of construction due to heating tubes or service lines in the slab at unknown locations. Additionally, insulation strips or forgotten grade stakes may be hidden from view by a sole plate or the slab itself, thereby preventing its identification as an infestation channel.

Regarding the first principle, the Termite Investigations Committee recommended that wood not contact the ground, untreated wood above the ground be supported by either concrete or wood that has been chemically treated, voids in masonry units be avoided and all cracks be filled with cement, ample ventilation be provided within the substructure, adequate soil drainage be provided beneath and around the structure, and a metal shield be provided as a barrier to runways under structural wood (Brown et al. 1934). Use of metal termite shields has since been reclassified as an inspection aid rather than a control measure, since termites will build tubes over the shields (Su and Scheffrahn 1990a, Lewis 1997).

Physical barriers that can be placed around foundation supports and building cavities (thereby making the structure inaccessible to subterranean termites) and cannot be crushed under the weight of slabs include granite or basaltic rock particles, wire mesh,

and insecticide-impregnated plastic. Rock particles consist of either crushed gravel or sand (Grace and Yamamoto 1993, Tamashiro et al. 1987, Ahmed and French 1996, Lewis et al. 1996). Su and Scheffrahn (1992) found that *R. flavipes* could not tunnel through rock particles ranging from 1.18 to 2.80 mm (effective particle size will vary with termite species). Rocks this size prohibited interstitial termite movement and are too big for the termites to manipulate with their mandibles (Ebeling and Pence 1957).

Australian Termi-mesh was developed from stainless steel wire in the early 1990s to act as termite barrier installed during the construction process (Lenz and Runko 1994). The mesh excludes termites because head capsules cannot fit through the screen (Grace et al. 1996, Kard 1998). Therefore, the mesh size needed to exclude termites will vary depending on species. It was originally intended to be a complete layer under the concrete slab (Ewart 2001). The high cost of quality steel was prohibitive and limited sales. To overcome this limitation, Termi-mesh sought and gained Australian recognition that a properly constructed slab, with predictable cracking sites made by scoring the slab, could also be a component of the barrier system (Ewart 2001). Mesh installation was then targeted to the perimeter, slab penetrations, and slab joints. This allowed the Australian company to grow its market share by reducing installation cost (Ewart 2001).

Use of the slab as a barrier, without any added mechanical or chemical devices, has also been explored. Australian researchers investigated subterranean termite movement through cracks in slabs of varying widths. They reported that cracks must be a sufficient size to accommodate the termite head capsule, plus additional width to allow body movement during tunnel construction (termites lined cracks with building (fecal) material; Lenz et al. 1997). For example, *Coptotermes acinaciformis*, an Australian pest

species, was able to penetrate 1.5 mm-wide cracks in concrete slabs (Lenz et al. 1997). Similar tests have not been published for North American subterranean termite species, but *R. flavipes* workers should presumably be able to travel through slab cracks of at least their body width, 1.11 mm (head capsule width of 1.03 mm; Su et al. 1991b). Cracks of this size may occur during normal settling of a structure over time (NPCA 1980).

Impasse (Syngenta Crop Protection, Greensboro, NC) is an insecticide-impregnated vapor retarder which contains the pyrethroid lambda-cyhalothrin within its polymer layers to repel termites from cracks in the slab or gaps created around utility penetrations (Harbison 2003). It is installed before the slab is poured and is intended to provide at least 10 years of protection (Harbison 2003). This product became available in 2002.

Addition of termiticides to concrete has been investigated. *Reticulitermes* did not tube over hardened concrete when either dieldrin or chlordane were added at the time of concrete mixing (Allen et al. 1961, Beal 1971). These insecticides, however, have been removed from the market due to environmental concern.

Referring to the second principle, the Termite Investigations Committee recommended using wood pressure-impregnated with chemical preservatives (discussed above) known to be toxic to termites (Brown et al. 1934). In areas where complete protection was not feasible, the Committee recommended use of either sound seasoned heartwood of an unpalatable species (discussed above); or wood treated with toxic chemicals by methods other than pressure–impregnation, such as spray, brush, or dip. Today's structural lumber is provided by softwood trees rather than hardwood. Therefore,

chemical treatment of wood is more common than using the hardwood of an unpalatable species.

As part of the third principle, the Termite Investigations Committee advised homebuilders to provide adequate soil drainage, remove all cellulose sources (e.g. stumps, roots, construction debris) in or on the ground near the structure, provide substructural ventilation for crawl spaces, and locate and destroy colonies based on swarming sites around the structure (Brown et al. 1934). For ventilation, the Committee specifically called for an opening of 2 sq ft for each 25 linear feet of structural perimeter (Brown et al. 1934). The Committee also recommended that wood floors have at least 18 inches of clearance between the joists and ground (Brown et al. 1934). The present-day Florida Building Code (FBC) calls for at least 1 sq ft for each 150 sq ft of crawl space that can be reduced by 10% if a vapor barrier is installed. Vapor barriers are required for slab-on-grade construction (FBC 2002). The FBC presently mandates at least 8 inches of clearance between the joists and ground (FBC 2002).

Termite protection principles for new construction were present in building codes as early as 1923. That year, Burlington, Iowa, had provisions in its building code to protect homeowners from poor construction that might lead to termite infestation (Snyder 1935). In 1927, the Pacific Coast Building Officials adopted recommendations of the Bureau of Entomology and Plant Quarantine ("Bureau") for structural prevention of termite damage as part of their uniform building code (Snyder 1935). Honolulu adopted similar recommendations in 1928 (Snyder 1935). In 1934, both the Federal Housing Administration and the Home Owner's Loan Corporation wrote specifications for prevention of termite damage to woodwork of buildings (Snyder 1935). The 1935

resolutions of the Building Officials of America supported adoption of the Bureau's structural termite prevention recommendations for the eastern United States (Snyder 1935).

Urban entomologists Smith and Zungoli influenced national building codes in the late 1990s (Zungoli 1999) after results from a survey of 225 South Carolina pest control companies indicated the below grade installation of rigid board insulation (RBI) increased risk of subterranean termite infestations and undetectable structural damage (1995a). Although termites gain no nutritional value from RBI (Hicken 1971), they will readily tunnel through the material (Guyette 1994, Smith and Zungoli 1995b, Rambo 1998). They reported that >12% of those surveyed had been involved in litigation concerning the issue (Smith and Zungoli 1995). RBI was not visible in 82% of the inspected South Carolina houses that reportedly contained RBI and had a history of unsolved termite problems (Smith and Zungoli 1995b). Damage to these houses was randomly located throughout the structure, as opposed to being concentrated in areas of excessive moisture or areas that are difficult to treat (Smith and Zungoli 1995b). Language prohibiting the installation of RBI below grade and specifying a 6 inch clearance between RBI and earth was adopted by the Council of American Building Officials (CABO), the Standard Building Code Congress International (SBCCI), and the International Code Council (ICC) in response to the RBI survey and inspection reports (Zungoli 1999).

In April 1996, St. Johns County, Florida, enacted construction regulation to reduce subterranean infestations. After convening with his appointed Subterranean Termite Treatment Committee, County Building Official Roland Holt, amended the building code to include a Termite Protection Ordinance, which was intended to decrease

subterranean termite food sources, eliminate hidden termite access into structures, increase efficacy of the chemical barrier underneath and around structures, and provide documentation of preconstruction termiticide treatment (Table 3-1). (The Ordinance is discussed in Chapters 3 and 4.) Several Florida counties later adopted similar regulations. Most of the St. Johns County Termite Protection Ordinance was approved for inclusion in the new statewide Florida Building Code, effective March 1, 2002.

Statement of Purpose

This research was conducted to examine the relationship between construction and subterranean termite infestation rates. First, the effect of concrete contamination on the residual performance of termiticides was determined. In laboratory experiments, the hypothesis that elevated soil pH due to masonry cement contamination degrades soil termiticide performance was tested using subterranean termite mortality as a chemical degradation indicator. Second, failure rates of termite prevention practices in three Florida counties were determined and correlation of termite infestations with certain building construction elements before and after building code changes was attempted.

CHAPTER 2

EFFECT OF ELEVATED SOIL pH FROM MASONRY CEMENT ON RESIDUAL SOIL TERMITICIDE PERFORMANCE

Introduction

An effective soil termiticide is expected to protect a structure from subterranean termite infestation for at least 5 years (Kard et al. 1989). Despite this industry standard, treatment failures still occur within that period. For example, 15.85% of houses 2-6 years old in St. Johns County, Florida, that received a soil termiticide treatment at the time of construction were infested as reported by homeowners (Chapter 3). Many factors can influence treatment failures, including termite abundance, termiticide concentration, type of active ingredient, product formulation, soil type, and chemical degradation (Macalady and Wolfe 1983, Felsot 1989, Forschler and Townsend 1996, Gold et al. 1996).

Residual activity of soil termiticides in known to decline over time. In Florida concrete slab tests, chlorpyrifos (Dursban, Dow AgroSciences, 10,000 ppm) failed in one of ten plots after 9 years (Kard et al. 1989). Cypermethrin (Prevail FT, FMC Corp., 500 ppm) failed in one of ten plots after 5 years, and permethrin (Dragnet FT, FMC Corp., 500 ppm) failed in two of ten plots after 4 years (Kard et al. 1989, Wagner et al. 2003).

Key factors that affect pesticide degradation include chemical, photochemical, and microbial degradation, leaching, run-off, volatilization, bioaccumulation in plants and animals (Rao et al. 1993), and size of area treated (Su et al. 1999a). Soil degradation rates have been determined for chlorpyrifos, bifenthrin, permethrin, and cypermethrin when

applied at termiticidal concentrations. In laboratory and field trials, half-lives in different soils ranged from 23 to 462 days for chlorpyrifos (analytical grade, Sigma, Racke et al. 1988; Dursban, Dow AgroSciences, 1,000 ppm in soil (wt/wt): Di et al. 1998, Baskaran et al. 1999, Su et al. 1999b, Murray et al. 2001); 5 to 1,410 days for bifenthrin (analytical grade, FMC Corp., 100 ppm in soil (wt/wt), Baskaran et al. 1999; Biflex FT, FMC Corp., 31 ppm in soil, Su et al. 1999b); 22 to 45 days for permethrin (Dragnet FT, FMC Corp., 50 ppm in soil (wt/wt), Su et al. 1999b); and approximately 12 days for cypermethrin (Prevail FT, FMC Corp. 30 ppm in soil (wt/wt), Su et al. 1999b).

Termiticides protect structures by either killing or repelling termites (Forschler 1999). Nonrepellent termiticides, such as chlorpyrifos (Dursban, Dow AgroSciences; Su et al. 1982 and 1995, Jones 1988) and imidacloprid (Premise 75, Bayer Environmental Science; Kuriachan and Gold 1998, Gahlhoff and Koehler 2001) allowed termites to penetrate treated soil but caused high mortality within 7 days. Greater than 90% of exposed *Reticulitermes flavipes* (Kollar) workers died within 7 days after penetrating 2.5 cm into 5 cm of soil treated with 100 ppm of chlorpyrifos (Dursban, Dow AgroSciences; Su et al. 1995). *Reticulitermes flavipes* completely penetrated 10 mm of soil treated with 10 ppm imidacloprid (Premise 75, Bayer Environmental Science; Gahlhoff and Koehler 2001). Pyrethroids, such as permethrin, cypermethrin, and bifenthrin, are strong repellents that caused < 30% mortality of *R. flavipes* workers that were exposed for 7 d to 2.5 cm treated segments but did not tunnel into them (Su et al. 1982 and 1995). Five cm of soil treated with any of these pyrethroids at only 1 ppm was enough to completely repel termites (Su et al. 1995). Degradation below this threshold concentration can result in termites penetrating treated soil and accessing a structure.

Soil pH can also affect termiticide degradation. Alkaline pHs caused degradation of chlorpyrifos (Racke et al. 1994, Baskaran et al. 1999), imidacloprid (Sarkar et al. 1999, Zheng and Liu 1999), fipronil (U.S. EPA 1996, Bobé et al. 1998), and pyrethroids (Camilleri 1984) in solutions. Gold et al. (1996) reported that 95% of the chlorpyrifos (Dursban TC, Dow AgroSciences) applied at 1,000 ppm in soil (wt/wt) of pH 8.2 had degraded within 2 years. Alkaline soils (pH 7.1 to 9.6) did not affect 50 ppm imidacloprid (Bayer Environmental Science) and 100 ppm bifenthrin (FMC Corp.), both >98% purity (Baskaran et al. 1999). Gold et al. (1996) studied the persistence of six termiticides for 5 years under field conditions and ranked them in the following order based on their persistence: permethrin > fenvalerate > bifenthrin > chlorpyrifos > cypermethrin > isophenphos. At soil pHs of 6.4 to 8.2, all termiticides originally applied at manufacturer recommended rates were found at less than half of their original concentrations at 1 year post-treatment (Gold et al. 1996). The lowest mortalities of *R. flavipes* caused by termiticide treatments occurred in alkaline soils (pH 7.1 to 8.2) compared to treatments in slightly acidic (pH 6.4) soil (Gold et al. 1996).

Construction practices may be an additional influence on termiticide performance. Masonry cement contamination in the vertical treatment zone around the perimeter of new construction may increase termiticide degradation. Portland cement is the most common masonry cement used in brick veneer mortar and cement foundations (Allen 1999). This cement consists of calcium carbonate and/or magnesium carbonate and, if mixed with moist Florida soil (Alachua County: loamy, siliceous, thermic Arenic Paleudults; Thomas et al. 1985), will probably increase soil pH when it hydrolyzes to calcium and/or magnesium hydroxide. The purpose of this study was to determine how much portland cement is needed to raise the pH of fine loamy sand to alkaline levels and

also to determine the effect of elevated pH on degradation of various concentrations of termiticides (chlorpyrifos, imidacloprid, fipronil, bifenthrin, permethrin, or cypermethrin) as indicated by 24 h mortality of *R. flavipes*.

Materials and Methods

Field Soil

Field soil was collected from 27 homes in Gainesville, Florida (A horizon soil: loamy, siliceous, thermic Arenic Paleudults; Thomas et al. 1985) for the purpose of determining the pH range for laboratory bioassays. Nine newly completed structures (<2 weeks old), nine 5-year old structures, and nine 10-year old structures were included. The nine structures in each age group were divided so that one-third of each were covered by either stucco, siding, or brick veneer. Soil 10 cm from structural walls was collected using a metal pipe (10.16 cm ID) inserted 20 cm deep into soil. Individual soil samples were shaken loose from the pipe into labeled, resealable bags. For each structure, one soil sample was taken from a randomly selected area.

Laboratory Bioassay Soil

Soil (approx. 10 lbs.) was collected from Gainesville (Alachua County), Florida, oven-dried (177°C for 24 h), and sieved (Fisher No. 16, Pittsburgh, PA). Soil was fine loamy sand (A horizon soil: loamy, siliceous, thermic Arenic Paleudults; Thomas et al. 1985).

Soil pH Determination

Field soil. Soil pH for samples taken from next to structures was determined with á pH-meter (Fisher No.13-620-290: Pencil Thin Gel Filled Combination Electrode with BNC, Hanna, Pittsburgh, PA) as per the protocol of the University of Florida Institute of

Food and Agricultural Sciences Soil Testing Laboratory. This method requires that 33 g soil (25 mL) and 50 mL distilled water be stirred together in a paper cup. One subsamples of each soil sample was used. The mixtures were left to stand for 30 min, then stirred again. Once the soil settled, the pH was determined.

Laboratory bioassay soil. The pH was determined for 3 subsamples of untreated bioassay soil as described for field soil. After initial pH determination, a weighed arbitrary amount of portland masonry cement (Quikcret®, Atlanta, GA), type "S", was then added to each 33– g soil sample, stirred, and left to stand for 30 min before pH re-determination. Soil and cement were handled this way until the quantities of cement needed to raise soil pH to 6, 7, 8, and 9 were determined.

Insecticides

Six termiticides, Dursban TC (44% chlorpyrifos; Dow AgroSciences, Indianapolis, IN), Premise 2 (21.4% imidacloprid; Bayer Environmental Science, St. Louis, MO), Termidor SC (9.1% fipronil; Aventis/BASF, Montvale, NJ), Talstar (7.9% bifenthrin; FMC Corp., Philadelphia, PA), Demon TC (25.3% cypermethrin; Syngenta Corp., Greensboro, NC), and Prelude (25.6% permethrin; Syngenta Corp., Greensboro, NC), were used in this study. Distilled water was used to make all insecticide dilutions and served as the control treatment (0 ppm insecticide). Three identical stock dilutions were prepared in 100 mL volumetric flasks for each termiticide to achieve the highest concentration tested when 3.3 mL of dilution was applied to 33 g soil (representing 10x the calculated termiticide concentration after application to soil at label rate). (See Appendix A for exact termiticide amounts added to distilled water). Three 1:10 serial dilutions were then made from each stock dilution.

Laboratory Bioassay Soil Treatments

Thirty-three g of soil were placed in individual plastic weigh boats (13 by 13 cm). The appropriate amount of portland cement was added to each weigh boat to prepare each pH level (6, 7, 8, and 9). Each stock dilution line served as a replication so that there were 3 replicates of each treatment combination: (6) termiticides, (5) concentrations, and (4) pH levels) for a total of 360 treatment units.

To incorporate the desired amount of active ingredient into the soil, 3.3 mL of dilution was added to 33 g soil/cement in weigh boats and stirred to uniformly moisten the mixture (10% moisture; Gahlhoff 1999) and attain concentrations of 10,000, 1,000, 100, 10, and 0 ppm (wt [AI]:wt soil) for chlorpyrifos and permethrin; 5,000, 500, 50, 5, and 0 ppm for cypermethrin; 600, 60, 6, 0.6, and 0 ppm for fipronil and bifenthrin; and 500, 50, 5, 0.5, and 0 ppm for imidacloprid. These concentrations include the manufacturers' recommended application rates (see Appendix B for label rate calculations for soil treatments) and equal 10x, 1x, 0.1x, and 0.01x the label rates in soil. The treated soils were air-dried in a hood for at least 5 d to allow solvents in the formulation to evaporate.

In addition to the treatment units, three controls (soil + cement) were prepared with distilled water for use as an assay for each soil pH (6, 7, 8, and 9) at each time interval (1 day, 5 months, and 10 months). Termites were not added to the controls. This resulted in a grand total of 396 units (360 bioassay units + 36 controls soil pH assay units).

Original weights were determined for all soil termiticide treatments and controls (soil + cement + liquid + weigh boat) and the first bioassay began 24 h later. After each bioassay, termites were removed, and soil was replaced and reweighed. Replaced soil was

reused at 5 and 10 month intervals. Distilled water was added every 7-10 days to maintain the original wet weights over the 10-month period.

Weigh boats were stacked in plastic tubs (one tub per chemical) with steel mesh screen between layers. Tubs were loosely covered with aluminum foil and kept in the dark at ambient room temperature and humidity.

Insects

Termites from three *R. flavipes* field colonies of were collected from PVC ground-tubes and plastic paint bucket traps on the University of Florida campus, Gainesville, Alachua County, Florida.

One colony was collected as described by Powell (2000) from a PVC ground-tube trap (11.5 cm diam. by 30.5 cm long) containing corrugated cardboard strips (236.0 cm long by 15.2 cm wide; Hesco, Waverly, FL), buried approximately 12 cm in the ground, and covered with a PVC cap (12.5 cm diam.; NIBCO, Elkhart, IN).

Termites from the other two colonies were collected as described by McManamy (2002). Each trap consisted of a plastic paint bucket (19.5 cm by 22 cm; Venture Packaging Inc. Monroeville, OH) monitor with lid buried in the ground. Holes (2 cm) were drilled in the sides and bottom of the buckets for termite access. The traps contained a roll of corrugated cardboard (236.0 cm long by 15.2 cm wide; Hesco, Waverly, FL) and a block of wood (3.5 cm thick, 8.5 cm wide, 14 cm long; *Pinus* spp.) with six grooves (3 mm wide, 1 cm deep, 1 cm apart) on one side to encourage termite exploration. The bucket was then concealed with groundcover.

Cardboard containing termites were removed and placed in clear plastic boxes (ca. 30 by 19 by 10 cm) containing a layer of damp paper towels and covered with a close-fitting lid. Boxes were labeled with colony name, collection date, and stacked inside 32-

gallon polyethelyne storage container (ca. 36 by 30 by 80 cm). Insects were held for up to 10 d at 23 ± 1°C and 94 ± 5% RH.

Data Collection and Research Design

Field soil. A single soil pH was determined for each structure. Each experimental unit for field soil pH determination consisted of field soil and distilled water in a weigh boat. This was a 3 x 3 factorial design (3 claddings x 3 ages).

Laboratory soil pH assay for bioassay soil. For controls, pH was determined for three 33 g samples of clean, dry soil, without cement. The pH of laboratory bioassay soil/cement mixed with distilled water was determined immediately after treatment and again after 5 and 10 months for 3 randomly chosen units for each of the four starting pH levels. Each experimental unit consisted of soil, cement, and distilled water in a weigh boat, replicated three times.

Bioassay. Bioassays were conducted at 5 days, 5 months, and 10 months after soil treatment. Each termite colony served as one replicate (n=3). For each termiticide a group of ca. 10 worker termites (undifferentiated larvae of at least the third instar), one each from three separate colonies, were each placed on 7 g treated soil and held in the dark in covered 29.57 mL plastic cups. Number of dead termites was counted at 24 h. All termites then removed from treated soil and the soil was returned to its respective weigh boat for reuse.

The experiments for each termiticide were a 5 (concentrations) x 4 (pH) x 3 (time intervals) factorial design replicated three times. Each experimental unit consisted of ca. 10 termites and treated soil/cement mixture in a plastic cup.

An additional bioassay was conducted at 10 mo. for 0, 5, and 50 ppm imidacloprid in soil in which termites were held in covered cups for 7 d, instead of 24 h,

so that full effect of imidacloprid could be realized . The experimental units were finely sprayed with distilled water every 24 h to prevent dessication. Three replications were made and mortality was recorded at 7 d. This was a 3 (concentrations) x 4 (pH) factorial design.

Data Analysis

Field soil pH sssay. The pH means, minimums, and maximums for soil located adjacent to Gainesville structures of different exterior claddings and different ages were determined. A two-way analysis of variance (ANOVA) was used to determine if there were significant interactions between the main effects: cladding type and age ($\alpha = 0.05$; SAS Institute 2000).

Laboratory soil pH assay. The relationship between cement weights and soil pH (6, 7, 8, and 9) at 5 d was determined by linear regression. Changes in pHs over time for pH assay soil were analyzed by one-way ANOVA, and mean pH levels at 0, 5, and 10 months were separated using Scheffe's Test ($\alpha = 0.05$; SAS Institute 2000).

Bioassay. For each termiticide, a three-way ANOVA was performed to determine significant interactions of main effects (pH, termiticide concentration, time interval) on termite mortality. When three-way interactions were significant and variation occurred among mortality means, two-way ANOVAs were used for each termiticide to determine the effect of concentration and pH on termite mortality at specific time intervals. Mean termite mortality at each time interval for each concentration and pH level for cypermethrin was reported because the three-way interaction was not significant. When two-way interactions were significant, one-way ANOVA was performed for each termiticide concentration and time period to determine differences between pH treatments. When the two-way interaction was not significant, mean percentage termite

mortality due to concentration was separated within time periods. At 10 mo., additional ANOVAs were performed to determine the effect of concentration and pH on mortalities of termites confined for 7 d on soil treated with 0, 5, and 50, ppm imidacloprid. Means were separated using Scheffe's Test (SAS Institute 2000). Percentage mortality was arcsine square-root transformed before all ANOVA , and α-level of 0.05 was used for all analyses. Mortality served as a measure of residual activity of soil termiticides.

The relationship between time period and pH on mean percentage termite mortality was estimated by linear regression (SAS Institute 2000) for the highest termiticide concentrations at which pH significantly affected mortality. Non-overlap of 95% confidence intervals of slopes were considered to be significantly different.

Results

Field Soil pH Assay

The pH of soil taken from 27 Gainesville structures ranged from 5.20 for 10-year-old stuccoed houses through 10.10 for new houses with brick veneer (Table 2-1). Soil was alkaline for all 5 year old structures. There was no significant interaction between exterior cladding and structural age, and neither main effect was significant (Cladding: df=2, MS=2.9633, F=2.82, P=0.0863; Age: df=2, MS=1.5478, F=1.47, P=0.2562; Cladding x Age: df=4, MS=1.4544, F=1.38, P=0.2797; Error: df=18, MS=0.0526; Table 2-1).

Laboratory Soil pH Assay

Soil pH before treatment was 5.6. The soil required less than 1% of its weight in cement to increase pH to 9.07 (Table 2-2 and Fig. 2-1). Soil pH did not significantly change during the first 5 months of being held in the laboratory. Soils of pH 7.02, 8.02,

and 9.07 significantly decreased to below neutral after 10 mo. Soil at pH 6.01 significantly increased to 6.53 at 10 mo. (See Appendix C for ANOVA table.)

Bioassay

No termites died from the control treatments. Cypermethrin caused >93% mortality at all three time periods for subterranean termites exposed to treated soil for 24 h compared with the other five termiticides. There were no significant interactions between cypermethrin concentration, soil pH, and time (Table 2-3). Only concentration had a significant effect on mortality of termites exposed for 24 h to cypermethrin-treated soil (Table 2-3). A two-way ANOVA was not performed for the cypermethrin treatments because the three-way interaction was not significant. Residual activity of cypermethrin was not significantly decreased by pH and $\geq$ 93.33% of the treated termites died with 24 h for all pH levels, cypermethrin concentrations and time intervals (Table 2-5).

All interactions and main effects significantly affected mortality of termites confined on soil treated with the other five soil termiticides: bifenthrin, permethrin, chlorpyrifos, fipronil, and imidacloprid (Appendix D). For bifenthrin and permethrin, all termites died within 24 h for all concentrations at 5 d. The interaction between concentration and soil pH, and main effects, significantly affected mortality at 5 and 10 months for bifenthrin and at 10 months for permethrin (Table 2-4) . Residual activity of both bifenthrin and permethrin at 0.01x the label rates (0.6 and 10 ppm, respectively) was significantly reduced by pH (Table 2-4). For bifenthrin, residual activity decreased at both the 5 and 10 month intervals (Table 2-6 and Appendix E), while permethrin's activity was significantly reduced at 10 months (Table 2-7 and Appendix E).

All termites exposed to chlorpyrifos died within 24 h for all concentrations at 5 d. The interaction between concentration and soil pH significantly affected mortality of termites confined to chlorpyrifos-treated soil at 5 and 10 months (Table 2-4). Soil concentrations of chlorpyrifos $\geq$0.1x the label rate were not significantly affected by pH as evidenced by complete termite mortality (Table 2-8 and Appendix E). Ten ppm chlorpyrifos (0.01x label rate) killed all termites at 5 d, but residual activity significantly declined in soil made alkaline by cement (Table 2-8 and Appendix E).

For the fipronil treatments, only concentration significantly affected termite mortality at 5 d. The concentration-pH interaction was significant at 5 and 10 months (Table 2-4). Fipronil killed all termites in soil treated at 6 ppm (0.1x label rate) at 5 d, but then mortality decreased significantly at alkaline pHs at 5 and 10 months (Table 2-9 and Appendix E).

Imidacloprid concentration significantly affected termite mortality at 5 d, and the concentration-pH interaction and both main effects were significant at 5 and 10 months (Table 2-4). Imidacloprid applied at the label rate (50 ppm) killed all termites within 24 h at 5 d (Table 2-10). For treatments aged 5 and 10 months, termite mortality was significantly reduced at all pH levels, with a mean of only 7.22% of termites dying from the label rate treatment at 10 mo. (Table 2-10 and Appendix E). However, at the 10 mo. and label rate all confined termites died within 7 d at all pHs (Table 2-10). No termites died within 24 h from 5 ppm imidacloprid (0.1x label rate) aged 10 mos., but 30.56% of the termites died after 7 d confinement on soil from the same treatment. (See Appendix F for ANOVA table for all termiticides.)

Linear regression analysis of termite mortality after 24 h exposure to treated soil aged 5 mo. indicated an inverse relationship between pH and termite mortality for

bifenthrin, chlorpyrifos, fipronil, and imidacloprid treatments (Fig. 2-2). Confidence intervals of slopes for these four treatments overlapped at 5 mo. (Fig. 2-2). Five ppm cypermethrin killed all termites at all pH levels (Fig. 2-2). At 10 mo., there was an inverse relationship between pH and termite mortality for bifenthrin, permethrin, chlorpyrifos, fipronil, and imidacloprid treatments (Fig. 2-3). Five ppm cypermethrin killed all termites within 24 h. pH had the greatest effect on residual activity of termiticides, at the concentrations presented in Figs. 2-2 and 2-3, in the following order: imidacloprid > fipronil > chlorpyrifos = bifenthrin > permethrin > cypermethrin.

Discussion

Field Soil pH Assay

The pH minimums of soil adjacent to new structures covered by either stucco or siding agreed with the normal pH range, 4.5 through 6.5, of Alachua County fine, loamy sand (Thomas et al. 1985). However, since alkaline soils are not normally found in the Alachua area, the high pH soil adjacent to new brick veneer work may have been due to the cement powder becoming mixed with the soil during the construction process. If so, this would result in varying levels of cement contamination throughout the soil. Cement mixed with moist soil raises soil alkalinity and may lead to subsequent hydrolysis of applied termiticides, thereby rendering them impotent (Naumann 1990).

Soil pHs 6, 7, 8, and 9 were chosen for the bioassay based upon the results of the field soil pH assay. Soil pH of 10 was not tested because soil from only one new brick veneer structure of that pH was detected after bioassay testing began.

Laboratory Soil pH Assay

The change in the control soil pH may have occurred due to a combination of microbial action and cation exchange capacity of the soil. Although soil was baked at a sterilizing temperature before use, it was not kept in a sterile environment. Therefore microbes could have aided in shifting the soil pH back towards its original slightly acidic level (Brady and Weil 1999). The biggest change in soil pH over the 10-month period was in soil that started at 9.07. This change was probably due to the cation exchange capacity of soil, which increases with soil pH (Brady and Weil 1999). Also, water was added to soil every 7-10 days so that evaporation occurred. This wet-dry regime also could have contributed to the slow pH change over time.

Bioassay

The lowest concentrations that killed all termites exposed to treated soil for 24 h at 5 d were 5, 0.6, and 10 ppm cypermethrin, bifenthrin, and permethrin, respectively. Similar results were reported by Smith and Rust (1990) who found 100% mortality of *R. hesperus* Banks confined on treated soil for 3 h. However, increased soil pH significantly reduced mortality of termites confined to soil aged for either 5 or 10 mo. and treated with either bifenthrin or permethrin at 0.6 and 10 ppm, respectively. These concentrations represent 0.01x the label rate for soil treatments. Efficacy of bifenthrin significantly decreased at the 5 month interval, while mortality of termites held on permethrin-treated soil did not decrease until the 10 month interval. Su et al. (1999b) also found that bifenthrin (formulated as Biflex) degraded faster than either permethrin (formulated as Dragnet) or cypermethrin (formulated as Prevail). Their study, however, did not

differentiate soil pH levels. In this study, termite mortality from 0.01x the label rate of both pyrethroids bifenthrin and permethrin decreased as soil pH increased.

In contrast to the other tested pyrethroids, cypermethrin soil concentrations surprisingly were not affected by soil pH within the 10 month period. The fluoride in the bifenthrin theoretically should have made it more stable in alkaline soil than either permethrin or cypermethrin which do not contain a fluoride constituent (Naumann 1990). Perhaps the different residual activities of these pyrethroids were affected more by their inert ingredients (Harris 1972, Naumann 1990) than by their active ingredients.

Chlorpyrifos at ≥ 10 ppm killed all termites within 24 h at all pH levels at 5 d. Smith and Rust (1990) reported that chlorpyrifos in soil at 50 ppm killed 100% of treatment-confined *R. hesperus* within only 7 h. Over the 10 month period, however, alkaline soil pH significantly decreased residual activity of the lowest tested concentration of chlorpyrifos in soil, 10 ppm (0.01x label rate). (Chlorpyrifos soil concentrations ≥100 ppm were not affected by pH.) This parallels a study conducted by Racke et al. (1994), who reported chlorpyrifos could have a half-life of only three months at 10 ppm in the alkaline soils of Florida and Texas, while a concentration of 1,000 ppm would retard hydrolysis. Murray et al. (2001) found that the stability of chlorpyrifos at 1,000 ppm is unaffected by natural soil alkalinity. The slower degradation of higher concentrations of chlorpyrifos probably occurred because the degradation product, 3,5,6-trichloro-2-pyridinol, is antimicrobial and retards further degradation by microbes (Somasundaram et al. 1990). Both permethrin and cypermethrin, before degradation, in sandy loam at 5 ppm were also antimicrobial (Naumann 1990).

Imidacloprid (Boucias et al. 1996, Kuriachen and Gold 1998, Gahlhoff 1999, Ramakrishnan et al. 2000, Gahlhoff and Koehler 2001) and fipronil (Gahlhoff 1999,

Osbrink et al. 2001) have been shown to be nonrepellent, slow-acting contact poisons. In this study, they were the only treatments that caused less than 100% mortality of termites at 5 d. Boucias et al. (1996) found at least three days exposure to soil treated with 50-100 ppm technical imidacloprid were needed before termites began dying. For fipronil, Osbrink et al. (2001) reported approximately 10-fold higher LT_{90}s for *R. virginicus* (Banks) compared to lethal times for termites exposed to chlorpyrifos, permethrin, or cypermethrin. Also, fipronil in sand, soil, and clay at 5 ppm required 5 to 10 d to cause 100% mortality of *Coptotermes formosanus* Shiraki in test tube tunneling assays (Osbrink and Lax 2002). Therefore, the 24 h exposures used in this study probably was not enough time for full expression of termite mortality from these slow-acting termiticides. All termites exposed for 7 d to label rate imidacloprid (50 ppm) at 10 mo. died at all pH levels. However, with only 24 h exposure full expression of imidacloprid toxicity was not realized, and pH seemed to affect termite mortality. Also, 5 ppm imidacloprid (0.1x label rate) killed 30.56% of the termites after 7 d confinement on treated soil, but no termites died within the first 24 h of confinement. Although no 7 d trials were run with fipronil, a longer exposure (>24 h) to treated soil should result in higher termite mortality (Osbrink and Lax 2002).

Chlorpyrifos (Racke et al. 1994) and pyrethroids (Naumann 1990) are degraded by hydrolysis under alkaline conditions. However, chlorpyrifos is more water soluble (chlorpyrifos water solubility [WS] ~0.73 ppm; Su et al. 1999b) than permethrin (WS ~ 0.006 ppm; Su et al. 1999b) and cypermethrin (WS <0.0001 ppm; Su et al. 1999b) and could have degraded faster than the two pyrethroids. In termiticide degradation studies using treated soil under miniature slabs, Tamashiro et al. (1987), Su et al. (1993b and

1999b), and Gold et al. (1996) reported faster degradation of chlorpyrifos compared with pyrethroids.

Toxicant adsorbs more readily to sand particles than clay or silt particles (Harris 1972). In general, increased organic matter (Smith and Rust 1990 and 1993) or increased silt or clay (Henderson et al. 1998b, Forschler and Townsend 1996, Gold et al. 1996) decreases insecticide efficacy. The greater surface area of colloids found in silt and clay increases chemical binding sites for termiticide adsorption and renders the toxicant as unavailable to termites. A substrate with many colloidal surfaces will cause decreased efficacy of applied termiticides (Smith and Rust 1990, 1993, Forschler and Townsend 1996, Gold et al. 1996) compared to the same termiticide applied to sand. The Alachua County fine loamy sand used in my study was 4-10% clay, 5-20% silt, and 70-85% sand, with 2-4% organic matter (Thomas et al. 1985). Adsorption of the different termiticides to soil particles, and their subsequent bioavailability to termites, may have been influenced by the chemicals' size, shape, conformation, configuration, polarity, polarizability, pH, charge distribution, and water solubility (Harris 1972). Additionally, the nature and properties of the organic and inorganic soil colloids could have also influenced termiticide adsorption to soil particles (Harris 1972).

Residual activity of very low initial soil concentrations for five of the termiticides tested were affected by alkaline pH. All affected concentrations were 0.1x to 0.01x of the label rates. These rates, however, are important because uniform distribution of termiticide in the soil is unlikely. The amount of termiticide recovered significantly varied between samples taken from different locations within the same treatment area after chemical and soil were blended in a concrete mixer (Kard and McDaniel 1993, Gold et al. 1996). In samples taken only 24 hours after mixing soil and termiticide, Kard and

McDaniel (1993) found 777 to 1071 ppm of chlorpyrifos (Dursban) originally applied to soil at a calculated concentration of 1,000 ppm; 374 to 568 ppm permethrin (Dragnet) was recovered from soil originally treated at 500 ppm; and 347 to 513 ppm cypermethrin (Demon) was recovered from soil originally treated at 250 ppm. Recovery variability was probably caused by non-uniform distribution of termiticide in the soil, resulting in some areas with high termiticide concentration and others with low concentrations.

Several factors influence the distribution of termiticides in soil. Horizontal penetration of termiticides in soil varied based on soil type. Beal and Carter (1968) found more than 11% of the dieldrin originally applied to Northern Florida soil moved downward 3.75 inches within 24 hours, while only 0.03% of the dieldrin moved to the same depth in Arizona soil (dieldrin applied at 2 pt/ft^2 sprinkled on top of soil). Differential vertical penetration of termiticides depended upon the chemical (Bennet et al. 1974), sample distance from the injection point (Davis and Kamble 1992, Davis et al. 1993), and quantity interacting with application pressure (Davis and Kamble 1992).

Low concentrations of termiticide, caused by non-uniform distribution, may occur in conjunction with cement added to the soil in the treated area. Soil moisture would hydrolyze the cement and free enough hydroxyl ions to increase soil pH, resulting in termiticide breakdown. An additional concern is that disruption or movement of treated soil due to construction activity may also lower the concentration of chemical. According to this laboratory study, addition of portland cement to soil treated with low concentrations of chlorpyrifos, imidacloprid, fipronil, bifenthrin, and permethrin degraded the termiticides as indicated by low termite mortality. Contamination within the termiticide treatment area around new construction could easily be reduced by use of a drop cloth to catch scrap cement.

Table 2-1. Range of soil pH levels for soil within 10 cm of structures covered by different exterior claddings located in Gainesville, Florida

Structure Age	Mean soil pH ± SEM (Min. to Max.)		
	Stucco (n=3)	Siding (n=3)	Brick Veneer (n=3)
< 2 weeks	6.47 ± 0.45 (5.60 - 7.10)	6.77 ± 0.64 (5.50 - 7.60)	8.90 ± 0.72 (7.60 - 10.10)
5 years	7.80 ± 0.26 (7.30 - 8.20)	7.83 ± 0.35 (7.20 - 8.40)	8.57 ± 0.26 (8.10 - 9.00)
10 years	7.80 ± 0.26 (5.20 - 8.40)	7.43 ± 0.69 (6.60 - 8.80)	7.27 ± 0.46 (6.50 - 8.10)

ANOVA resulted in no significant interaction between cladding and age, and no significant differences in mean soil pH between houses of different claddings or ages. (Two-way ANOVA: Cladding df=2, MS=2.9633, F=2.82, P=0.0863; Age df=2, MS=1.5478, F=1.47, P=0.2562; Cladding x Age df=4, MS=1.4544, F=1.38, P=0.2797; Error df=18, MS=0.0526)

Table 2-2. Amount of portland cement needed to raise pH of 33 g fine loamy sand from 5.60 to 9.07 and the change in pH of aged sand held in the laboratory and treated with distilled water

mg cement added	% of sand	n	Starting pH 1 Day	Ending pH (Mean ± SEM) 5 Months	Ending pH (Mean ± SEM) 10 Months
0.0	---	3	5.60 ± 0.02	-----	-----
15.0	0.05	3	6.01 ± 0.02a	6.34 ± 0.19ab	6.53 ± 0.06b
47.6	0.14	3	7.02 ± 0.01a	7.21 ± 0.11ab	6.58 ± 0.16b
148.0	0.45	3	8.02 ± 0.01a	8.02 ± 0.15a	6.69 ± 0.12b
291.0	0.88	3	9.07 ± 0.01a	8.93 ± 0.09a	6.97 ± 0.04b

Means within a row followed by the same letter are not significantly different ($\alpha = 0.05$, Scheffe's Test). See Appendix C for the ANOVA table.

Table 2-3. Three-way ANOVA of the effects of concentration, pH, and time on the mortality of termites confined on soil treated with cypermethrin (Demon TC)

Source	df	MS	*F*	*P*
Conc (C)	4	17.6534	11084.70	< 0.0001
pH	3	0.0011	0.71	0.5471
Time (T)	2	0.0030	1.87	0.1592
pH X T	6	0.0011	0.71	0.6411
C X pH	12	0.0011	0.71	0.7830
C X T	8	0.0030	1.87	0.0715
C X pH X T	24	0.0011	0.71	0.8319
Error	120	0.0016		

Percentage termite mortality was arcsine square-root transformed before analysis. No two-way ANOVA of cypermethrin was required because 3-way interaction was insignificant.

Table 2-4. Two-way ANOVA of the effects of concentration and pH on the mortality of termites exposed for 24 h to soil the same day, or 5 and 10 mos. after it was treated with currently registered termiticides

Treatment	Time	Source	df	MS	*F*	*P*
Bifenthrin (Talstar)	5 Mo.	Conc (C)	4	6.3498	1437.56	< 0.0001
		pH	3	0.0541	12.24	< 0.0001
		C X pH	12	0.0541	12.24	< 0.0001
		Error	40	0.0044		
	10 Mo.	Conc (C)	4	6.4627	1201.62	< 0.0001
		pH	3	0.0981	18.25	< 0.0001
		C X pH	12	0.0981	18.25	< 0.0001
		Error	40	0.0054		
Permethrin (Prelude)	10 Mo.	Conc (C)	4	6.6425	3756.62	< 0.0001
		pH	3	0.0388	21.92	< 0.0001
		C X pH	12	0.0388	21.92	< 0.0001
		Error	40	0.0018		
Chlorpyrifos (Dursban TC)	5 Mo.	Conc (C)	4	5.5533	515.01	< 0.0001
		pH	3	0.0641	5.94	0.0019
		C X pH	12	0.0641	5.94	< 0.0001
		Error	40	0.0108		
	10 Mo.	Conc (C)	4	5.5574	56926.50	< 0.0001
		pH	3	0.1618	1657.17	< 0.0001
		C X pH	12	0.1618	1657.17	< 0.0001
		Error	40	0.0001		

Table 2-4 Continued

Treatment	Time	Source	df	MS	F	P
Fipronil (Termidor SC)	5 Days	Conc (C)	4	5.7451	12619.80	< 0.0001
		pH	3	0.0008	1.84	0.1550
		C X pH	12	0.0008	1.84	0.0738
		Error	40	0.0005		
	5 Mo.	Conc (C)	4	5.1817	2316.53	< 0.0001
		pH	3	0.4442	198.59	< 0.0001
		C X pH	12	0.1678	75.02	< 0.0001
		Error	40	0.0022		
	10 Mo.	Conc (C)	4	5.0640	1090.22	< 0.0001
		pH	3	0.2946	63.43	< 0.0001
		C X pH	12	0.1234	26.56	< 0.0001
		Error	40	0.0046		
Imidacloprid (Premise 2) 1 Day	5 Days	Conc (C)	4	7.4064	43397.60	< 0.0001
		pH	3	0.0001	0.98	0.4102
		C X pH	12	0.0001	0.98	0.4805
		Error	40	0.0002		
	5 Mo.	Conc (C)	4	5.2820	1262.97	< 0.0001
		pH	3	0.0990	23.67	< 0.0001
		C X pH	12	0.0402	9.62	< 0.0001
		Error	40	0.0042		
	10 Mo.	Conc (C)	4	5.6207	2688.79	< 0.0001
		pH	3	0.0146	6.98	0.0007
		C X pH	12	0.0146	6.98	< 0.0001
		Error	40	0.0021		

Table 2-4 Continued

Treatment	Time	Source	df	MS	*F*	*P*
Imidacloprid	10 Mo.	Conc (C)	2	7.5674	6057.89	< 0.0001
(Premise 2)		pH	3	0.0087	7.00	0.0015
7 days		C X pH	6	0.0087	7.00	0.0002
		Error	24	0.0012		

Percentage termite mortality was arcsine square-root transformed before analysis. Control mortality was 0%. No two-way ANOVA of cypermethrin was required because 3-way interaction was insignificant (Table 2-3).

Table 2-5. Mean percentage mortalities (24h) of termites held on soil treated with cypermethrin (Demon TC)

Soil Concentration	n	pH	5 Days	5 Months	10 Months
5,000, 500, and 50 ppm	3	6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	7	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	8	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	9	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	12	Mean	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
5 ppm	3	6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	7	100.00 ± 0.00	100.00 ± 0.00	93.33 ± 6.67
	3	8	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	9	100.00 ± 0.00	100.00 ± 0.00	97.67 ± 2.33
	12	Mean	100.00 ± 0.00	100.00 ± 0.00	97.75 ± 1.72
0 ppm	3	6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	7	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	8	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	9	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	12	Mean	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table 2-6. Mean percentage mortalities of termites held on soil treated with bifenthrin (Talstar)

Soil Concentration	n	pH	5 Days	5 Months	10 Months
600,60,	3	6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
and	3	7	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
6 ppm	3	8	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	9	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	12	Mean	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	6	100.00 ± 0.00	63.33 ± 1.93a	74.23 ± 7.76a
0.6 ppm	3	7	100.00 ± 0.00	48.90 ± 1.10ab	40.00 ± 10.00ab
	3	8	100.00 ± 0.00	20.10 ± 7.59bc	18.90 ± 6.75bc
	3	9	100.00 ± 0.00	10.00 ± 5.77c	2.23 ± 2.23c
	12	Mean	100.00 ± 0.00	35.58 ± 6.80	33.84 ± 8.68
0 ppm	3	6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	7	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	8	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	9	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	12	Mean	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Percentage termite mortality was arcsine square-root transformed before analysis.

Table 2-7. Mean percentage mortalities of termites held on soil treated with permethrin (Prelude)

Soil Concentration	n	pH	5 Days	5 Months	10 Months
10,000, 1,000, and 100 ppm	3	6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	7	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	8	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	9	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	12	Mean	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
10 ppm	3	6	100.00 ± 0.00	100.00 ± 0.00	51.10 ± 1.10a
	3	7	100.00 ± 0.00	100.00 ± 0.00	31.13 ± 2.94ab
	3	8	100.00 ± 0.00	100.00 ± 0.00	17.77 ± 2.23bc
	3	9	100.00 ± 0.00	100.00 ± 0.00	5.57 ± 2.94c
	12	Mean	100.00 ± 0.00	100.00 ± 0.00	29.39 ± 5.19
0 ppm	3	6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	7	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	8	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	9	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	12	Mean	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Percentage termite mortality was arcsine square-root transformed before analysis.

Table 2-8. Mean percentage mortalities of termites held on soil treated with chlorpyrifos (Dursban TC)

Soil Concentration	n	pH	5 Days	5 Months	10 Months
10,000, 1,000, and 100 ppm	3	6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	7	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	8	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	9	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	12	Mean	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
10 ppm	3	6	100.00 ± 0.00	100.00 ± 0.00a	100.00 ± 0.00a
	3	7	100.00 ± 0.00	88.90 ±11.10ab	100.00 ± 0.00a
	3	8	100.00 ± 0.00	74.47 ± 4.00 ab	52.23 ± 2.23b
	3	9	100.00 ± 0.00	54.43 ± 15.54b	28.90 ± 1.10c
	12	Mean	100.00 ± 0.00	79.45 ± 6.63	70.28 ± 9.31
0 ppm	3	6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	7	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	8	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	9	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	12	Mean	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Percentage termite mortality was arcsine square-root transformed before analysis.

Table 2-9. Mean percentage mortalities of termites held on soil treated with fipronil (Termidor SC)

Soil Concentration	n	pH	5 Days	5 Months	10 Months
600 and	3	6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
60 ppm	3	7	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	8	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	3	9	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	12	Mean	100.00 ± 0.00a	100.00 ± 0.00	100.00 ± 0.00
6 ppm	3	6	100.00 ± 0.00	86.67 ± 1.93a	97.77 ± 2.23a
	3	7	100.00 ± 0.00	92.23 ± 2.23a	57.77 ± 2.23b
	3	8	100.00 ± 0.00	92.00 ± 1.00a	44.53 ± 5.90bc
	3	9	100.00 ± 0.00	18.67 ± 7.22b	21.10 ± 2.20c
	12	Mean	100.00 ± 0.00a	72.39 ±9.53	55.29 ± 8.52
0.6 ppm	3	6	62.20 ± 1.10	66.67 ± 0.00a	83.33 ± 3.84a
	3	7	53.33 ± 2.67	66.67 ± 0.00a	61.13 ± 5.57ab
	3	8	63.43 ± 2.02	65.47 ± 1.23a	52.23 ± 2.94bc
	3	9	62.00 ± 4.00	1.00 ± 1.00b	22.23 ± 8.00c
	12	Mean	60.74 ± 1.48b	49.97 ± 8.53	54.73 ± 7.00
0 ppm	3	6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	7	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	8	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	9	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	12	Mean	0.00 ± 0.00c	0.00 ± 0.00	0.00 ± 0.00

Percentage termite mortality was arcsine square-root transformed before analysis.

Table 2-10. Mean percentage mortalities of termites held on soil treated with imidacloprid (Premise 2)

Soil Concentration	n	pH	5 Days	5 Months	10 Months (1 day)	10 Months (7 days)
500 ppm	3	6	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	---
	3	7	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	---
	3	8	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	---
	3	9	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	---
	12	Mean	100.00 ± 0.00a	100.00 ± 0.00	100.00 ± 0.00	---
50 ppm	3	6	100.00 ± 0.00	71.10 ± 10.93a	10.00 ± 0.00a	100.00 ± 0.00
	3	7	100.00 ± 0.00	54.43 ± 4.43ab	11.10 ± 1.10a	100.00 ± 0.00
	3	8	100.00 ± 0.00	39.97 ± 3.33b	7.77 ± 4.00ab	100.00 ± 0.00
	3	9	100.00 ± 0.00	32.20 ± 1.10b	0.00 ± 0.00b	100.00 ± 0.00
	12	Mean	100.00 ± 0.00a	49.43 ± 5.19	7.22 ± 1.59	100.00 ± 0.00
5 ppm	3	6	44.43 ± 1.13	28.87 ± 7.27a	0.00 ± 0.00	43.33 ± 3.33a
	3	7	47.77 ± 2.23	12.23 ± 2.93ab	0.00 ± 0.00	28.90 ± 1.00ab
	3	8	44.43 ± 1.13	8.90 ± 2.20b	0.00 ± 0.00	25.57 ± 2.94b
	3	9	46.67 ± 1.93	0.00 ± 0.00c	0.00 ± 0.00	24.43 ± 4.43b
	12	Mean	45.83 ± 0.84b	12.50 ± 3.60	0.00 ± 0.00	30.56 ± 2.65
0.5 and 0 ppm	3	6	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	7	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	8	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	3	9	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	12	Mean	0.00 ± 0.00c	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Percentage termite mortality was arcsine square-root transformed before analysis.

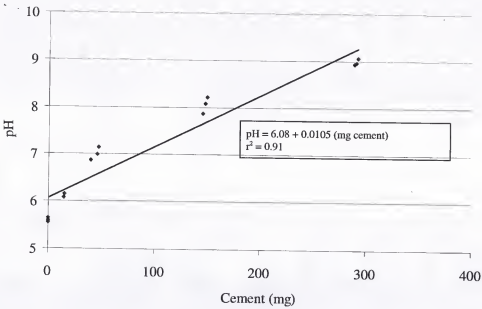

Figure 2-1. Relationship between amount of cement in soil and pH of mixture.

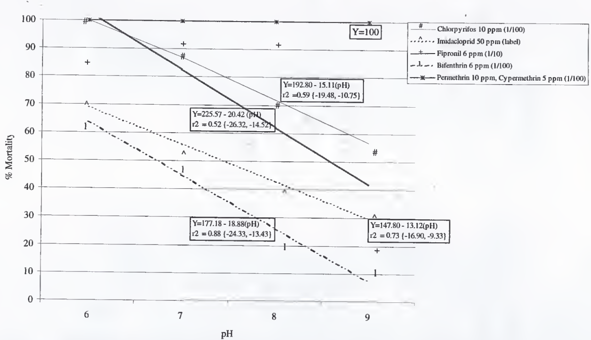

Figure 2-2. Mortalities (24 h) of *R. flavipes* confined on soil of pH 6, 7, 8, or 9, treated with termiticides, and aged 5 months. Confidence intervals (95%) for slopes are in { }.

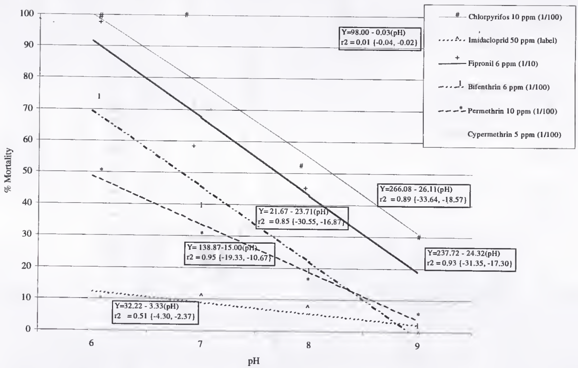

Figure 2-3. Mortalities (24 h) of *R. flavipes* confined on soil of pH levels 6, 7, 8, or 9,treated with termiticides, and aged 10 months. Confidence intervals (95%) for slopes are in { }.

CHAPTER 3
A SURVEY OF NORTHEAST FLORIDA HOMEOWNERS REGARDING SUBTERRANEAN TERMITE INFESTATIONS

Introduction

Although subterranean termites are ecologically important as decomposers of cellulose material, they are considered pests in urban habitats. Their cryptic habits make control difficult and allow them to cause hidden damage to structures. The elements necessary for subterranean termite infestations are moisture, cellulose, and structural access.

Subterranean termites are vulnerable to desiccation and require access to a supply of moisture. Water content of *R. flavipes* nest material was reported to range from 16.3 to 67.7% and relative humidity within their galleries was reported to be 100% (Sponsler and Appel 1990). If away from the high humidity within the colony, most termites can only survive in air close to its water vapor saturation point (Rudolph et al. 1990). Inside the colony, moist soil and fecal deposits throughout the galleries maintain the required high moisture (Potter 1997). Eastern subterranean termite workers are ~75% water (Sponsler and Appel 1990) and maintain their water content by either withdrawing capillary water from the soil or drinking free water (Rudolph et al. 1990). In the urban environment, factors that may provide high soil moisture, and create ideal habitats for subterranean termites around buildings, include mulch, sprinkler irrigation, roof run-off, gutter downspouts, and air conditioner condensation drip lines (Haagsma and Rust 1995).

Subterranean termites can survive in a variety of substrates and moisture contents. Haverty (1979) reported 75 to 82% survival of *R. flavipes* in 8-week laboratory bioassays using sand (9 to 17% moisture by weight), vermiculite (100 to 500% moisture by weight), and combinations of the two (43 to 63% moisture by weight). Vermiculite substrates were less suitable for *R. virginicus*, but survivorship was highest in the sand and combination substrates (65 to 77% and 75 to 79% survival, respectively; Haverty 1979).

The moisture requirement of subterranean termites is met partially by their own metabolism and by the moisture diffusing through the soil in their galleries (Rudolph et al. 1990). Ambient relative humidity and moisture content of occupied wood are less important for maintaining water content of individual termites that are still connected to their humid underground galleries (Rudolph et al. 1990). Subterranean termites use tunnels to explore the soil environment. Grube and Rudolph (1999) speculated that the feces and soil lining of their tunnels serves to conserve humidity.

When in soil with an acceptable moisture content, subterranean termite workers also transfer moisture to their feeding sites (Su and Scheffrahn 1991 (obs.), Kirton et al. 1998 (obs.), Grube and Rudolph 1999). Additionally, they can form aerial colonies as long they have a constant source of moisture (Ratner 1963, Potter 1994), such as from a roof leak. *Reticulitermes flavipes* workers survived without any soil contact >189 days in pine blocks with 26% wood moisture content (McManamy 2002). Areas in a structure where moisture may build up due to condensation, such as kitchens and bathrooms, are particularly susceptible to subterranean termite infestations (Snyder 1948).

Subterranean termites will feed on any palatable cellulose-containing material in and around a structure, including living and dead trees, form boards or grade stakes, or the wood frame and contents of the structure itself. Even wood preservatives may not

prevent damage to structures since Formosan subterranean termites have been known to excavate through wood treated with chromated copper arsenate despite losing many workers (Wilcox 1984). Su and Scheffrahn (1991) found that subterranean termites consumed the centers of wood beams that were treated with 2,500 ppm borate spray. In choice tests with untreated wood, Duryea et al. (1999) found both *R. flavipes* and *R. virginicus* preferred feeding on sapwood versus heartwood. Feeding on mulches by subterranean termite workers was also investigated. No-choice tests with mulches indicate that both *R. flavipes* and *R. virginicus* did not feed on melaleuca mulch, while feeding and survivorship was high for pine, cypress, and eucalyptus mulches (Duryea et al. 1999).

Subterranean termites can enter structures through cracks in the foundation (Meder 2000), or from behind exterior cladding , stucco that extend below grade(NPCA 1980), and/or insulation (Smith and Zungoli 1995a and b). *Coptotermes acinaciformis* workers crawled through 1.5 mm-wide cracks in concrete slabs (Lenz et al. 1997). Cracks this wide may occur during normal settling of a structure over time (NPCA 1980). Different slab types may also play a role in allowing termites to enter a structure, as supported and floating slabs have more access points for termites than single-pieced monolithic slabs (NPCA 1980). Cracks in the mortar of brick masonry or cracked stucco shrinking away from the frame could also direct foraging termites in a structure (Snyder 1948).

In Florida, structural protection against subterranean termites begins with soil termiticide treatments during the construction of a house. This "preconstruction" treatment is done in several steps: first, horizontal and interior vertical soil treatments are completed within the formed foundation before the concrete slab is poured; second,

exterior vertical treatments are applied to soil adjacent to where any slabs are to be poured; finally, another exterior vertical treatment is placed around the perimeter of the house after completion of landscaping. The soil termiticides currently used are categorized into three groups (Su et al. 1982): type I, primary toxic repellents, such as fenvalerate, bifenthrin, permethrin, and cypermethrin (Su and Scheffrahn 1990b); type II, toxic but not necessarily repellent, such as chlorpyrifos (Su et al. 1982, Su and Scheffrahn 1990b), which has been withdrawn from the market due to environmental concerns; and type III, slow-acting toxicants which are nonrepellent, such as imidacloprid (Kuriachan and Gold 1998), fipronil (Osbrink et al. 2001), and chlorfenapyr (Wagner et al. 2003). Most soil termiticides are required to provide wood protection for 5 years in at least 3 United States Department of Agriculture Forest Service (USDA-FS) field sites before EPA and state registrations are granted (Kard et al. 1989, Wagner 2003). (Fast-tracked candidates may require fewer years.) Nevertheless, preconstruction treatment failures are common due to improper treatments, disturbance of the treated soil, or construction that may provide termites hidden access into the structure (pers. obs.). Also, homeowners may disrupt termiticide barriers by digging up treated soil or by allowing gutter downspouts or air conditioner condensation to drip or discharge onto termiticide treated soil. Termites can breach treated soil through untreated gaps (Forschler 1994, Kuriachan and Gold 1998).

Mandatory preconstruction treatment is a very recent requirement by the State of Florida. The new state-wide building code went into effect in March of 2002 and was modeled after a change in the building code of St. Johns County (St. Augustine area, northeast Florida). The chief building official of St. Johns County appended a Termite Protection Ordinance (TPO) to the county code, effective April 28, 1996, in an effort to

reduce the following conditions that are conducive to subterranean termite infestations: wood-to-ground contact, hidden termite access to structures, and moisture around the foundation.

The effects of the St. Johns County building code change, and subsequently the state-wide Florida Building Code, on reducing subterranean termite infestations are undocumented. The purpose of this study was to use a survey to determine how the TPO of St. Johns County affected subterranean termite infestation rates, construction types, and house maintenance characteristics. County and pest management professional (PMP) treatment records were inspected to evaluate the effects of house age, political boundary, preconstruction chemical soil treatment, and other factors relating to soil moisture, cellulose around the foundation, and hidden subterranean termite access on structural infestation rates.

Materials and Methods

Survey Population

The survey was conducted in three coastal, contiguous Northeast Florida counties. Political boundaries were Flagler County, St. Johns County, and Jacksonville Beach in Duval County. The survey was mailed to all single-family houses built between 1994 and 1998, totaling 12,868 surveys (7,147 to St. Johns County, 5,113 to Flagler County, and 608 to Jacksonville Beach). Surveys were considered to be delivered to homeowners if they were not returned unopened and marked as undeliverable by the postmaster. Delivered surveys totaled 12,027.

Houses built between 1994 and 1998 in St. Johns County were used in the survey to determine the effect of the county building code change, effective in 1996, on

subterranean termite infestation rates. Houses from the northern and southern adjacent counties, Duval and Flagler, respectively, built within the same time period were chosen for comparison.

Survey Method and Format

A written survey, cover letter, and business-reply postage-paid return envelope were mailed in May, 2000 to all single-family homes built between January 1, 1994 and December 31, 1998. For identification, each survey was marked with the building permit number corresponding to the mailing address. The cover letter was on University of Florida letterhead, briefly explained the survey rationale, and identified the University of Florida as the research institution, and provided contact information. It requested homeowners to complete and return the survey in the envelope provided. To induce homeowner participation, the text of the cover letter included an incentive: construction and home maintenance practice recommendations for reducing termite infestations resulting from this research were to be mailed to survey participants (Appendix G). Homeowners were promised anonymity with regard to any publications resulting from this research. All mailed material was photocopied text on white paper. Survey question answers were either multiple choice, fill in the blank, or list format. The homeowner was asked to mark those aspects which occurred on or around the house (Fig. 3-1).

Survey questions regarding type of foundation, frame, and exterior cladding were chosen to categorize houses and illustrate construction trends over political boundaries and time. Questions relating to subterranean termite access, wood proximity to the foundation, and water near the foundation were chosen based upon factors that influence subterranean termite infestation likelihood. The questions about exterior perimeter

inspection gap, air conditioner condensation drip line, gutter downspout, and irrigation and lighting lines were phrased to reflect the TPO appended to the St. Johns County Building Code, effective April 28, 1996, which mandated a minimum distance of 2 feet from the foundation for these structural features. (See Table 3-1 for a list of modifications to the St. Johns County Building Code. The TPO was amended again in 1998 (Table 3-1). Features mandated by the second amendment were not applicable to this research.

House Classifications and Survey Answers

Houses were classified according to political boundary, age, building code (1996 TPO) for houses in St. Johns County, and vertical preconstruction chemical soil treatment. Political boundary was determined by address. Age was defined as year home construction began and was determined by county-issued building permit number. Building code for houses in St. Johns County was also determined by building permit number. Vertical preconstruction soil chemical treatment information was available for 53.60% of the respondent houses (from pest control companies and county building records). (More records contained vertical treatment information instead of horizontal treatment information, so only vertical treatment data was included for analysis.) Survey response and infestation rates are provided for houses classified according to political boundary, age, and building code for St. Johns County houses. Infestation rates are also provided for houses classified by vertical preconstruction treatment.

Infestation rates are also provided for houses according to responses to questions regarding construction type and maintenance (Fig. 3-1). Questions regarding construction included identification of foundation type, frame type, and exterior cladding type.

Maintenance questions included those regarding inspection gap, bathroom plumbing access port, sprinklers, and identification of items within 2 feet of the foundation.

Construction type frequencies among houses were categorized by political boundary, age, building code for houses in St. Johns County, and preconstruction soil chemical type. Cladding types defined as stucco included those covered with shell-dash. Siding exteriors included all paneling (i.e. vinyl, aluminum, wood, concrete). Brick veneer included houses covered with stone veneer.

Influence of the Building Code Change on St. Johns County Houses

Influence of the St. Johns County Building Code change was evaluated for three house characteristics: gutter downspout discharge length, air conditioner condensation drip line discharge length, and bottom foundation perimeter inspection gap around houses with exterior cladding other than veneer. Those characteristics were the only building code changes for which the mailed survey was used to verify implementation.

Types of Subterranean Termite Evidence in Infested Houses

Infested houses were categorized by type, location, and time infestation evidence appeared, as noted on the survey by respondent homeowners. Homeowners may have indicated more than one type and/or location of infestation evidence. Types of infestation evidence were either alates, damage, or mud tubes. Locations included doorframe, window frame, bathroom, kitchen, fireplace, foundation, roof, and inside walls. Time for evidence to manifest was defined as amount of time, in years, from start of house construction until evidence of subterranean termites was noticed. Among infested houses, amount of time until evidence of infestation was classified by both preconstruction soil chemical treatment type and type of evidence.

Pest Control Company Public Relations

Homeowner knowledge of the pest control company that pre-treated their home was compared among houses of different ages and different political boundaries. Contract renewal rate was determined for homeowners who knew who their preconstruction treatment pest control company was.

Survey Verification

The survey was evaluated for bias and robustness. Survey bias was detected by comparing both house classifications and survey answers from voluntarily returned surveys with respective classifications and survey answers collected from 100 homeowners surveyed by telephone. Homeowners contacted by telephone had received the mailed survey but did not complete and return it. Clarification of survey questions to homeowners was provided if needed. Telephone surveys were divided so that 50 telephone calls were made to St. Johns County and 25 calls each were made to Flagler County and Jacksonville Beach. These homeowners were chosen by random number generation (SAS Institute 2000).

Survey robustness was evaluated by determining correct answers to survey questions regarding construction type and maintenance characteristics verified during site inspections of 35 infested premises belonging to St. Johns County homeowners who voluntarily answered the mailed survey. Inspections were conducted July through August 2001 for all premises to which access was granted by homeowners. With the exception of year construction began, respective homeowner survey answers were verified by both inspecting each of the 35 premises and interviewing homeowners. Construction years were identified by building permit number, not by respondents' answers.

Analysis

Respondent houses were classified as "infested" if homeowners answered "yes" to the question of infestation on either the returned survey or telephone survey. Houses for which homeowners answered "no" or "don't know" to the question of infestation were classified as "non-infested", indicating that homeowners had not found evidence of subterranean termites in their homes. Houses for which that question was left unanswered were not included in the analysis. Answers from telephone surveys were pooled with answers from voluntarily returned surveys for all analyses, except those relating to survey bias.

Differences in proportions among classification frequencies and answers to individual survey questions regarding construction and maintenance from both voluntarily returned and telephone surveys were detected at the 10% significance level for either the chi-square test or Fisher's exact test (SAS Institute 2000) when total number of houses to be included in analysis was >200. Analysis was performed at the 5% significance level when total number of houses to be included in analysis was $\leq$ 200. Fisher's exact test was performed in lieu of chi-square tests when tables contained expected cell frequencies $\leq$ 5 (Schlotzhauer and Littell 1997).

Results

Survey Response Rates

Of the delivered surveys, 2,486 (20.67%) were completed by homeowners and voluntarily returned. Response rates significantly differed among both political boundary and house age (Table 3-2). Among political boundaries, St. Johns County returned the highest proportion of delivered surveys (22.36%). Within St. Johns County, however,

response rates did not vary by building code (Table 3-2). Within the entire surveyed area, there was a significant trend among homeowners of newer houses to return more delivered surveys than homeowners of older houses.

Infestation Rates

Infestation rates significantly differed among political boundary, house age, and building code for St. Johns County houses (Table 3-2). While St. Johns County and Jacksonville Beach to the north had similar infestation rates (15.85% and 17.60%, respectively), Flagler County (southernly adjacent to St. Johns County) had a lower infestation rate among surveyed houses (2.70%). Among houses of different ages, newer houses tended to have lower infestation rates. The largest increase in infestation rate occurred between 3 and 4 year old houses; 4 year old houses had 3x the rate of 3 year old houses. Within St. Johns County, infestation rates also significantly differed by building code, probably due in part to the confounding effect of house age.

A highly significant association occurred between vertical preconstruction treatment and infestation rates: 15.89% of houses treated with repellent chemicals were infested compared to a 9.00% infestation rate among those treated with nonrepellent chemicals (Table 3-3). (Vertical preconstruction treatment information was available for 1,386 out of the 2,586 survey respondents. Therefore, only 120 out of the 300 infested houses were included in this analysis.) Further statistical analysis revealed significance to lie within the repellent chemicals with significantly different infestation rates among termiticides within the group (Table 3-3). Conversely, nonrepellent treatments did not have significantly different infestation rates, possibly because almost all treatments (96.3%) were chlorpyrifos.

Amount of time needed for evidence of infestation to be found by homeowners of houses treated with repellent compared to nonrepellent soil termiticides was not significantly different at the 5% significance level ($P = 0.0716$, Fig. 3-2). However, a trend was observed for repellent chemicals to fail sooner than nonrepellent chemicals. The median and mode for time to evidence of subterranean termites was between 2 and 3 years for repellent termiticides and between 3 and 4 years for nonrepellent termiticides.

Infestation rates also differed significantly among certain construction and maintenance features (Table 3-4). The infestation rate of wood frame houses was almost five times higher than that of concrete block houses, and houses covered with combination siding/stucco had the highest infestation rate among the different cladding types (23.53%). Infestation rates were significantly higher for houses with wet exterior walls due to sprinklers, and for houses that had air conditioner condensation drip lines, gutter downspout discharge, or trees/shrubs/stumps within 2 feet of the foundation. Access to inspect bathroom plumbing was also significantly associated with infestation rate.

The infestation rate of concrete slab houses (11.66%) was not significantly different from the rate among crawl space houses (11.63%). Presence of a perimeter inspection gap, gutter type, and sprinkler/irrigation/lighting lines, mulch, wooden fence post, and firewood within 2 feet of the foundation all had no significant effect on infestation rates.

Construction Types

Foundation, frame, and exterior cladding types significantly differed among political boundaries (Table 3-5). Most respondent houses (98.10%) were concrete slab-

on-grade, with the highest frequency in Flagler County. This county also had the highest frequency of above-ground basements (0.24%), and Jacksonville Beach had the highest frequency of crawl space foundations (2.48%). For wall construction, 53.55% of houses were made of wood frames. However, while there were more wood frame than concrete block houses in both St. Johns County and Jacksonville Beach, the opposite occurred in Flagler County. Among exterior cladding types, stucco was most prevalent (66.58%). While the majority of houses in both Flagler and St. Johns Counties were stuccoed (70.42% and 66.69%, respectively), Jacksonville Beach had almost the same number of houses with stucco cladding (37.29%) as with exterior siding (33.90%) .

Houses classified by age had significantly different proportions of foundation and frame types, while exterior cladding types did not differ (Table 3-6). The frequency of concrete slabs increased slightly in newer construction: 97.95% in 6 year old houses to 98.68% in 2 year old houses. The frequency of concrete block walls, however, increased more dramatically in newer construction: 35.16% in 6 year old houses to 53.71% in 2 year old houses.

Within St. Johns County, most houses had concrete slabs (97.64%), with wood frames (72.34%), and stucco cladding (66.69%). Only wall construction significantly differed by building code (Table 3-7), with a trend towards more concrete block houses and less wood frame houses in newer construction.

Among both repellent and nonrepellent preconstruction soil treatments, most houses had concrete slabs (98.41%), wood frames (68.72%), and stucco (67.51%; Table 3-8). However, proportions of both wall construction and exterior cladding types significantly differed among treatments. More wood frame houses were treated with repellent than nonrepellent termiticides (73.87% versus 63.64%, respectively). More

stucco houses were treated with nonrepellent than repellent termiticides (69.61% versus 65.40%, respectively).

Influence of the Building Code Change on St. Johns County Houses

The new St. Johns County building code contained provisions to increase discharge distances of both gutter downspouts and air conditioner condensation drip lines from the foundation, and mandate an inspection gap around the bottom perimeter of houses covered with cladding other than brick or stone veneer. Results of the survey indicated that gutter downspout discharge distance did not change in accordance with the building code, while both air conditioner condensation drip line discharge distance and presence of an inspection gap did (Table 3-9). However, even though the code changes seemed to influence drip lines and inspection gaps, >43% of the surveyed houses in St. Johns County built after the TPO took effect did not meet the new code requirements.

Types of Subterranean Termite Evidence in Infested Houses

The evidence most frequently cited by homeowners was subterranean alates (47.77%), and the most frequently cited area was a window frame within the interior of the house (23.39%; Table 3-10). Types of evidence were found in significantly different proportions around and inside houses. Alates were found more often on an inside window than any other location. Most damage was reported in door frames, adjacent to slabs and inside windows and interior walls. The highest proportion of mud tubes were associated with foundations.

Alates, damage, and mud tubes (>28%) were most frequently found by homeowners between 3 and 4 years after construction began (Fig 3-3). Evidence of

infestation was noticed within one year of construction in approximately 7 to 10% of the infested houses.

Pest Control Company Public Relations

Most homeowners were able to identify the pest control company that treated their home during the construction process (88.53%) and most renewed that contract (82.23%; Table 3-11). Homeowner knowledge of their pretreatment pest control company significantly differed among house ages and political boundaries (Table 3-11). More homeowners of newer than older houses and more homeowners in St. Johns County than both Flagler County and Jacksonville Beach knew the pest control company that pre-treated their homes.

Owners of infested houses within the surveyed area relied on professional pest control services to protect their homes from further subterranean termite damage. The survey indicated that 97.83% (270 out of 276 owners of infested houses who answered the survey question) called for professional remedial service and 95.56% maintained the warranty on that work. According to homeowners who answered the question, mean treatment cost was $\$1,075.78 \pm 120.22$, with a median of \$850, and a range of \$0 (work was covered by the original preconstruction contract) to \$8,500. Mean damage repair cost was $\$907.73 \pm 139.39$, with a median of \$400, and a range of \$0 to \$5,000.

Survey Verification

Among houses classified by political boundary, significantly higher proportions of voluntarily returned surveys came from Flagler and St. Johns Counties versus phone surveys, while a lower proportion of surveys were returned by homeowners in Jacksonville Beach than those surveyed by phone (Table 3-12). Chi-square analysis found

no significant difference in proportions of voluntarily returned surveys and phone surveys classified by age. Proportions of both foundation types and exterior cladding types significantly differed, with most types occurring in greater proportions among voluntarily returned surveys than phone surveys (Table 3-12).

Among other survey questions, bias (indicated by higher proportions of positive answers among phone surveys than returned surveys) was found for air conditioner condensation drip line, wooden fence post, firewood, trees/ shrubs/ stumps, pest control contract renewal, and the question of subterranean termite infestation (Table 3-13). Homeowners answered "don't know" most frequently (20.29%) to the question regarding bathroom plumbing inspection access.

As for survey robustness, mean percentage of correct answers was 84.08% for structural physical attributes verified by site inspections (Table 3-14). All homeowners correctly identified their homes' type of foundation, frame, and cladding, and all were able to identify whether or not firewood was < 2 feet from their foundation. The least reliable survey question, of which only 20% of homeowners answered correctly, was presence or absence of access to inspect bathroom plumbing (Table 3-14). Most homeowners were unable to identify their bathroom inspection ports. The second least reliable question was that of construction year. Among all surveyed homeowners, only 64% answered this question correctly after verification using building permit numbers. Therefore true construction year as indicated by permit number was used to classify these houses correctly, instead of using survey answers.

Discussion

Survey Response Rates

While many factors affect mail survey response rates, salience of the questionnaire topic to the survey audience was one of the strongest (Heberlein and Banmgartner 1978, Goyder 1982). When included as a predictor variable used during their meta-analysis (quantitative analysis of contribution of independent factors to response rates) of 98 independent published studies, Heberlein and Baumgartner (1978) reported their salience scale to be directly correlated with return rates. For example, non-salient mailed surveys had 42% response while surveys judged to be salient had 77% return (Heberlein and Baumgartner 1978). However, salience is debatable among social scientists, since it is more subjective rather than objective (Goyder 1982, Fox et al. 1988).

Subterranean termites appeared salient in St. Johns County, considering the history of the area. Public concern over the termite problem in the County led to amendment of the St. Johns County Building Code with the TPO (Shaheen 1996). Therefore, it is not surprising that the return rate from St. Johns County was higher (62.71%) than those of Flagler County (33.27%) and Jacksonville Beach (4.02%; Table 3-2). Perhaps St. Johns County homeowners knew about subterranean termites before, either from personal experience or from the local media. The difference in response rates from homeowners of different-aged houses was probably due to a lower number of owners of older houses who could correctly answer questions. Perhaps they misplaced or forgot specific information about their homes which led them to disregard the survey.

Survey response rate, 20.67%, was low compared with those published from other mail surveys. However, direct comparison with those response rates is difficult, since

social scientists send their surveys to target populations. For example, surveys sent exclusively to professionals and university-educated persons achieved approximately 18% and 5.5%, respectively, higher return than surveys sent to others (Goyder 1982). Male populations yielded higher returns than female-only or mixed populations, and responses were 13% lower in urban areas than in rural or mixed populations (Goyder 1982). This survey did not target any specific demographic. The surveyed population, although not assessed, was assumed to be a mixed group; it included both urban and rural residents, and men and women of different ages and education levels.

In addition to salience, other factors that increase mail survey response rates include repeated contacts (Goyder 1982, Fox et al. 1988), inclusion of a stamped reply envelope (Linsky 1975, Armstrong and Lusk 1987, Fox et al. 1988, Yammarino et al. 1991), postage type (Linsky 1975, Yammarino et al. 1991), incentives (Linsky 1975, Fox et al. 1988, Yammarino et al. 1991), sponsorship (Heberlein and Baumgartner 1978, Fox et al. 1988), and length and appearance of the questionnaire (Heberlein and Baumgartner 1978). Anonymity and confidentiality did not to influence response rates (Yammarino et al. 1991, Groves et al. 1997). Researchers should be able to increase their response rates by mailing a cover letter that includes appeals or incentives with a survey of less than four pages (Yammarino et al. 1991). Surveys longer than four pages reduced response rates by 7.8%, while both appeals and reply envelopes increased response rates by 4.7% and 7.9%, respectively (Yammarino et al. 1991). Institutional versus commercial sponsorship also increased survey return rates (Fox et al. 1988). For institution-sponsored surveys, inclusion of stamped/metered return envelopes increased response rates by 6.1% (Yammarino et al. 1991). However, first class return postage, as opposed to the more cost-effective business reply rate, was reported to increase response rates by 9%

(Armstrong and Lusk 1987). Green paper versus white paper resulted in a range of effects, varying from a decrease in response rates of 5.6% to an increase of 9.1% (Fox et. al 1988). This survey was moderately salient, institutionally-sponsored, less than four pages, and included an incentive and a business-reply return envelope. Response rates might have increased had follow-up phone calls been made to homeowners who did not return the survey, or if first-class stamps been included instead of business-class rate.

Infestation Rates Among House Classifications and Construction Types

The three surveyed areas each have similar environments and are on the Atlantic coastline. For each, sandy soils predominate to a depth of 76.20 cm (30 in), average temperature is approximately 20.56°C (69° F), and average rainfall is approximately 1.35 m (53 in) (Readle et al. 1983, Readle et al. 1997, Watts et al. 1998). The climate is subtropical with long, warm, humid summers and mild winters. Approximately 60% of the rainfall occurs June through October (Readle et al. 1983, Readle et al. 1997, Watts et al. 1998).

Given the close proximity of houses to each other within the surveyed area, the differences in infestation rates in Jacksonville Beach / St. Johns County versus Flagler County was unexpected (Table 3-2). These may have been due to termite pressure, which was not measured and may have been influenced by previous land use.

Another explanation for these different rates may be differences the in construction types, as each had different proportions of foundations, wall construction, and exterior claddings. (Foundation type, however, was not significantly associated with infestation rates.) Wall construction also differed among political boundaries. Flagler County, for example, had more houses made of concrete block walls than wood frames,

which is opposite of St. Johns County and Jacksonville Beach. The strong association between frame type and infestation status indicated that the lower infestation rate in Flagler County could have been due to the decreased number of wood frame houses compared with the other two areas.

Houses covered with a combination siding/stucco cladding had the highest infestation rate. While this may have been an artifact of small sample size of these houses, of important note is that Jacksonville Beach, which had the highest overall infestation rate, also had the highest percentage of siding/stucco houses.

The construction process itself may have disrupted existing subterranean termite colonies by destroying either part of or the entire colony during land clearance. Homes with evidence of infestation in less than 3 years may have been built over an existing colony. Any portion of the colony not decimated during construction could continue as a satellite of the original colony. Pawson and Gold (1996) reported that *R. flavipes* and *R. virginicus* pseudergates separated from colonies differentiated into supplemental reproductives and produced eggs and nymphs within five and seven months, respectively. Therefore, it is not surprising that infestations were reported shortly after construction began.

Additionally, higher infestation rates occurred in older houses probably because foraging termites are more likely to find an entrance to a structure with time. Henderson et al. (1998a) reported that, after 13 months, approximately 50% more stakes placed in areas around structures assumed to be conducive to subterranean termites (prone to high moisture or had readily available cellulose sources) were attacked versus stakes placed in undirected patterns. Presumably, termites would have continued to forage in conducive areas and may have eventually gained structural access.

Another explanation for the differences in infestation rates of older verses newer houses has to do with wall construction. While almost 5x more wood frame houses were infested than concrete block houses, less of the newer homes were built with wood frames. Therefore, since infestation is more likely to occur in wood frame houses, perhaps infestation rates were higher for older houses because more of them had wood frames.

Wood frames of slab-on-grade houses are usually within 20 cm (~8 in) of the ground (Allen 1999). The close proximity of wood frames to the ground and the cryptic nature of subterranean termites with their ability to crawl through small cracks (Lenz et al. 1997) make untreated wood in frame houses easily accessible.

The higher infestation rates in St. Johns County according to building code is probably an artifact of time. The new building code took effect in 1996, four years before this survey was conducted. The decrease in rates, from 27.79% for houses built under the old code, to 7.10% for houses built under the new code (Table 3-2), reflected the decreased rates of 4 year old houses versus 2 to 3 year old houses. Also, the higher proportion of wood frame versus concrete block houses built under the old code may have also influenced infestation rates in older houses.

Survey results revealed that repellent soil termiticides were less effective than nonrepellents as pre-treatments. Among repellents, excluding both bifenthrin and fenvalerate, which had small sample sizes, cypermethrin performed better than permethrin. The three nonrepellents performed similarly, although this may have been an artifact of small sample sizes for fipronil and imidacloprid.

Variable performance levels were reported for repellent termiticides as a group by Wagner et al. (2003) in Florida USDA-FS field tests. For concrete slab tests, cypermethrin (0.5%) provided 5 years of 100% efficacy, fenvalerate (0.5%) provided 3

years, permethrin (0.5% Dragnet) provided 6 years, and bifenthrin (0.062%) provided 16 years (Wagner et al. 2003). Nonrepellent termiticides performed consistently, however, as chlorpyrifos (0.5% and 1.0%), imidacloprid (0.05%), and fipronil (0.06%) all provided at least 5 years of 100% protection of wood within concrete slabs (Kard 2000). (These formulations and concentrations reflect the majority of repellent termiticides and concentrations used for vertical preconstruction treatments of respondent houses (Appendix H)).

Different infestation rates among the two termiticide treatment types could have also been caused by wall construction bias, as wood framed houses comprised 73.87% of repellent treatments, but only 63.64% of the nonrepellent treatments (Table 3-8). Proportions of brick exterior claddings on repellent-chemical houses were also higher than on nonrepellent-chemical houses, which may have also contributed to bias. Brick sidings had higher infestation rates than houses with no brick, excepting siding / stucco combination houses (Table 3-4). Additionally, variability in either repellent or nonrepellent treatments could have resulted from applicator errors or formulation differences. Therefore, different proportions of frame and exterior cladding types, possible human error, and formulation differences make it difficult to conclude with certainty if nonrepellent chemicals out-performed repellent chemicals.

Statistical analysis of the 120 infested houses for which termiticide treatment type was known indicated that there was no significant difference at the 5% significance level between the time for evidence to manifest in houses treated with repellents versus nonrepellents. However, there seemed to be a trend for homeowners of repellent termiticide–treated houses to find termite evidence sooner than their nonrepellent cohorts. This data must be interpreted cautiously since more homeowners surveyed by telephone

indicated their homes were infested compared to those who voluntarily returned the survey by mail.

Difference in time to failure, if any, could have been due to the nature of the chemicals. Repellents form a barrier between the structure and the termite colony, without killing the insects. Nonrepellent treatments kill the termites after they contact the treated soil. *Reticulitermes flavipes* foragers continuously tunnel, and will change tunneling direction after contacting soil treated with repellent chemicals (Forschler 1994). This could ultimately lead termites to find a gap in the treatment. The minimum gap size in a repellent soil treatment that *R. flavipes* located varied between 3 and 4 cm (Kuriachan and Gold 1998), a width that could easily result from soil disturbance, such as that caused by gutter downspout discharge or growing tree roots. Perhaps, repellent termiticide failures were seen sooner than the nonrepellent termiticides because low termite mortality enabled more surviving foragers to locate gaps. Another explanation could be that some pyrethroids were applied at the low label rate which did not obtain 5 years of control in USDA-FS field trials.

Infestation Rates Among House Maintenance Characteristics

Maintenance characteristics that were moisture-related and inquired of homeowners on this survey included if sprinklers wet the house, gutter type, air conditioner condensation drip line length, gutter downspout length, and if mulch is < 2 ft from the foundation. Only sprinklers, gutter downspouts, and air conditioner condensation drip lines were significantly associated with infestation rates (Table 3-4). For the sprinklers and drip line, consistent irrigation during hot weather probably maintained the soil moisture necessary for termites to continue exploiting a resource

(Haagsma and Rust 1995). Water from the gutter downspout, may have eroded enough treated soil to allow termites access to a structure without affecting the colony. Lack of gutters was not significantly associated with infestation rates perhaps because bare roofs may cause rainwater to spread at the roof drip line, which is outside the area of vertical soil treatment. Lack of significant association between infestation and mulch near the foundation was unexpected, since mulched soils are presumed to buffer against temperature changes and conserve moisture more then bare soils (Fraedrich and Ham 1982, Smith and Rakow 1992). This buffering effect may be superficial; according to a study done by Long et al. (2001), neither organic nor inorganic mulch affected either temperature or moisture level in the soil at 12 cm below the surface. This survey did not discern between organic and inorganic mulches -- all houses with mulch near the foundation were pooled. According to NPMA (1999), mulch supposedly discourages termite activity by speeding soil drainage and drying.

Among structurally-associated cellulose sources in the survey, wall construction had the only significant association with infestation. Firewood, wooden fence post, and mulch were not significantly associated with infestation. This suggests that neither firewood nor a wooden fence post led to infestation in houses aged 2 through 6 years, although these features occurred with low frequency. Also, although organic mulch is a cellulose source, it provides inadequate nutrition for subterranean termites (Duryea et al. 1999, Long et al. 2001), perhaps leading the termites to feed on other materials.

For house characteristics which allow for visual identification of termite infestation or are related to termite access, only bathroom plumbing access port and trees/shrubs/stumps near the foundation were significantly associated with infestation. The bathroom plumbing access port was marginally significant ($P = 0.0979$) and the high

rate of don't know's and non-answers (20.53%) made this surveyed characteristic unreliable because homeowners may not have understood the question. For the trees/shrubs/stumps, perhaps the root systems served as guidelines to cracks in building foundations. Decomposed root systems from stumps may have created pre-formed tunnels. Irrigation and lighting lines in the ground near a structure, although potential guidelines for termites, were not significantly associated with infestation. This is consistent with results of Pitts-Singer and Forschler (2000), who found that laboratory cultures of both *R. flavipes* and *R. virginicus* almost always followed pre-formed tunnels, but did not follow wires as readily. Not surprisingly, presence of a foundation perimeter inspection gap was also not significantly associated with infestation rate, probably because it only allows early detection and is not a deterrent.

Influence of the Building Code Change on St. Johns County Houses

St. Johns County enacted the TPO in hopes of reducing subterranean termite infestations in new houses (Shaheen 1996). This survey indicated that gutter downspout length did not change when the new code took effect, and 63.08% of houses built after April 1996 had downspouts that did not comply with the new law. There were also less houses built with air conditioner drip lines near the foundation after the code changed, but 43.01% still did not meet code the requirement. Significantly more houses were built with the required foundation perimeter inspection gap after the new code went into effect than were built before the code change. However, only 44.06% of the houses met this building code specification.

These results indicate that surveyed St. Johns County houses were not constructed according to the Ordinance for two out of the three code requirements evaluated in this

survey. This was verified by site inspections of 35 infested premises in St Johns County, as explained in Chapter 4 (Table 4-2). In fact, none inspected houses that were built in 1997 met the Ordinance requirements for any measurements (Chapter 4). If the new building code requirements did not influence these visible characteristics, compliance with code requirements not visible after construction was completed, such as burial of wood away from the structure or veneer bearing ledge poured integrally with the main foundation, may have also been low (See Table 3-1 for St. Johns County Building Code changes).

Types of Subterranean Termite Evidence in Infested Houses

Homeowners cited alates as the most frequent evidence of subterranean termite infestation. In a survey of Kentucky homeowners, less than 19% mentioned mud tubes as evidence of infestation, while 56% mentioned damaged wood and 39% mentioned swarms (Potter and Bessin 2000). Therefore, it is not surprising that damage and alates were more frequently cited than mud tubes in this survey.

In an unpublished phone survey (Shimberg Center, Policy and Management Research, 2001) commissioned by the Florida Department of Agriculture and Consumer Services (FDACS), alates were the most common sign of infestation. Mud tubes were cited as the second most common sign of evidence, and damaged wood the third. This differs from the current survey, in which homeowners indicated evidence as occurring from highest to lowest: alates > damage > mud tubes. Differences could be due to sample size: 300 (out of 2,586 survey respondents) versus 41 (out of 602 interviews) for the FDACS survey. Also, the definition of damage may have differed between the two

surveys. Both damaged wood and exit holes in walls made by swarmers counted as damage in the current survey, while the FDACS survey included only damaged wood.

Most homeowners found termite evidence inside their homes associated with a window. This is not surprising since alates are attracted to light (Snyder 1948). On outside facing walls, exterior landscaping may have disturbed the perimeter soil treatment and allowed termites to cause damage or construct tunnels. For houses where the evidence was found on the exterior, most was in or near a door frame, including those in garages and patios. These door frames are associated with abutting slabs or driveways where cold joints are formed. Termite infestations in door frames may be the result of inadequate termiticide application or disturbance of termiticide treated soil prior to the pouring of secondary slabs abutting the main foundation.

Pest Control Company Public Relations

Most homeowners (88.53%) were able to identify the pest control company that treated their home during the construction process, and most renewed their contract with that company (82.23%; Table 3-11). Differences due to age of house and political boundary in the percentages of homeowners who knew the company that did the termiticide pre-treatment were probably due to local building codes. The St. Johns County TPO required a Notice of Treatment to be secured on or near the fuse box in the house. Therefore, it was not surprising that a greater percentage of owners of newer houses knew the company. Also, as expected, more homeowners in St. Johns County knew of their original pest control company compared with those living in the other surveyed areas.

The FDACS survey (Shimberg Center, Policy and Management Research, 2001) also reported a high percentage (80.2%) of homeowners who knew their homes were treated for subterranean termite control at the time of construction. However, only 41.8% were able to name the treating company. This survey differed in that it was conducted state-wide with homes ranging from 1 to 10 years old.

Owners of infested houses within the surveyed area relied on professional pest control services to protect their homes from further subterranean termite damage, as demonstrated by the high percentage of homeowners who called for professional service (97.83%) and maintained the warranty on that work (95.56%). In a nation-wide survey of 1,100 homeowners, Bayer Crop Science reported that only 72% of the homeowners who had a termite problem called for professional service (Harbison 2000). Perhaps the discrepancy between the two surveys was due to the differences in the two geographical areas. These numbers, however, demonstrate that professionals have a large share in the termite control market, in spite of availability of over-the-counter consumer products for subterranean termite control.

Survey Verification

Bias occurred among political boundary and was due to different ratio of voluntarily returned versus phone surveys for the three areas (Table 3-12). For future surveys, phone surveys among different political boundaries should be in equivalent ratio to mailed surveys. Among construction types, bias occurred for foundation and exterior cladding types and was probably caused by the different proportions of construction types among political boundaries.

Among survey questions, bias occurred for air conditioner condensation drip line, wooden fence post, firewood, trees, shrubs, and stumps, and pest control contract renewal, and the question of subterranean termite infestation (Table 3-13). Although explanation of survey questions was minimal while conducting phone surveys, the bias detected by the chi-square tests indicate that perhaps an explanation was given during phone surveys that was not given by the mailed survey. The significantly lower infestation rate among homeowners who voluntarily returned the survey (11.65% infested) versus those surveyed by phone (18.00% infested) indicated that perhaps infestations were underestimated. Homeowners who had infestations in their current homes may have been more inclined to reveal this while on the phone as opposed to marking it on the mail-in survey.

This survey had a robustness of 84.08% for structural physical attributes that were verified during site inspection of 35 houses (Table 3-14). Most homeowners were able to correctly answer the survey questions (> 77%), with the exception of bathroom plumbing access and year construction began. The numbers of homeowners who answered "don't know", left the question unanswered, and answered incorrectly indicate that further explanation of this character would be needed if used on future surveys. Additionally, the researchers would have to record information for each bathroom in the house. Also, for reliability of future surveys, the year construction began should be identified by building permit number, or other county-issued number. Some homeowners surveyed by phone needed further explanation to correctly answer this question, and homeowners who voluntarily returned the survey may have actually answered with their move-in date. Without inclusion of these two questions the survey robustness would have been 89.01%.

Overall Survey Remarks

This survey indicates that subterranean termite infestation was strongly associated with older wood frame houses. Although the data are not conclusive, houses treated with different repellent preconstruction termiticides had significantly different infestation rates and failed sooner than nonrepellent termiticides.

Changes to the St. Johns County Building Code, as written in 1996 and 1998, may not decrease the County's infestation rate due to incomplete compliance. Better compliance and additional code requirements should lower the subterranean termite infestation rates. This surveyed evaluated only three factors addressed by the Code, two of which were significantly associated with infestation rate: air conditioner condensation drip lines and gutter downspout length. A third moisture-related factor, sprinklers wetting the house, was not addressed by the Code but was significantly associated with infestation rate. Additionally, wood framing and cladding type, which were both significantly associated with infestation rate, were not addressed by the new Code. These factors should be considered in future Code amendments. The new Code, however, increased consumer awareness of original pretreatment pest control company.

Table 3-1. Modification to the St. Johns County Building Code, the Termite Protection Ordinance (TPO).

Subject	Standard Building Code [1]	TPO [2], April 28, 1996	TPO [3], July 22, 1998
Natural wood, vegetation, dead roots, stumps, trash, debris of things of similar nature that could reasonably be expected to attract organisms destructive to structures	Material shall be removed from foundation area and fill shall be clean. {Sec. 2301.1.2}	Not allowed to remain on building lot or underground within 5 ft of structure. Fill shall be clean. (Exception: living trees outside the roof line) {Sec. 2304.6.1.1}	Same.
Construction materials made from wood (grade stakes, forms, contraction spacers, tub trap boxes, plumbing supports, posts, organic or termite susceptible construction material)	Loose wood, debris and wood forms shall be completely removed from all spaces under building. (Exception: wood members of pressure-treated or naturally resistant wood) {Sec. 2301.1.3 & 2304.2.2}	Materials must be placed in obvious location for later removal. Material cannot be willfully buried within 15 feet of building. (Exception: posts of pressure-treated or naturally resistant wood, <8 in dimension, installed >6 in from structure for inspection and retreatment) {Sec. 2304.6.1.2}	Same.
Debris inside cells and cavities of masonry units	Not specified.	Free of debris before placement of concrete. (Exception: inorganic plugs and clean earth fill) {Sec. 2304.6.1.3}	Same.
Bottom perimeter inspection space of foundation sidewall exterior	6 in space required between wood siding and earth. (Exception: pressure-treated or naturally resistant wood) {Sec. 2304.2.5}	6 in space required below any wood, siding, felt, wire lath, sheathing, foam board or expanded polystyrene (included stuccoed framed posts or columns) down to top of sod, mulch, or soil. (Exception: paint or stucco adhered directly to masonry foundation) {Sec. 2304.6.2.1}	Same, but 4 in space above concrete or paving allowed.

Table 3-1 Continued

Subject	Standard Building Code [1]	TPO [2], April 28, 1996	TPO [3], July 22, 1998
Bearing ledge for brick or stone veneer	Not specified	Shall be poured integrally with the concrete foundation. (Exception: veneer may be carried by a structural metal member secured to foundation sidewall, 6 in inspection required above soil, sod, or mulch) {Sec. 2304.6.2.2}	Same, but a physical termite barrier must bridge wall sill plate to mortar joint.
Sleeves around piping through concrete slab-on-grade floors	Any material not harmful to concrete permitted. {Sec. 1907.3.1}	Must be non-cellulose, tightly closed at both ends by wire twists, tape wraps, or stainless steel hose clamps. {Sec. 2304.6.2.3}	Same.
Placement of decks, fences, patio, planters, or other building components	Not specified.	Must not abut foundation sidewall so as to obstruct 6 in inspection space. (Exception: components with >18 in ground clearance) {Sec. 2304.6.2.4}	Same.
Pre-construction soil chemical treatment for prevention of subterranean termites.	Not specified, at discretion of local building official.	Initial horizontal treatment to occur after all excavation, backfilling, and compaction is completed. Retreatment is mandatory if any soil disturbance occurs after initial treatment. Manufacturer recommendations on label must be followed. {Sec. 2304.6.3.1}	Same.
Material for plumbing traps or other boxed-out spaces	Not specified.	Must be created with permanently placed metal, solid plastic, or masonry forms of adequate depth so as not to disturb soil treatment. {Sec. 2304.6.3.2}	Same.

Table 3-1 continued.

Subject	Standard Building Code [1]	TPO [2], April 28, 1996	TPO [3], July 22, 1998
Vapor retarder	Placed beneath slab, minimum 0.152 mm polyethylene with joint lapped 152 mm and sealed, or other approved material. {Sec. 1909.2}	Chemically treated soil covered by vapor retarder within 1 h of treatment. Retreatment of soil mandatory if disturbance occurs. {Sec. 2304.6.3.3}	Same.
Concrete overpour or mortar excess accumulated along exterior foundation perimeter	Not specified.	Shall be removed prior to vertical soil treatments. {Sec. 2304.6.3.4}	Same.
Pre-construction soil chemical treatment under adjacent slab, vertical soil chemical treatment	Not specified, at discretion of local building official.	Horizontal treatment shall be applied under all exterior concrete on grade within 1 ft of the primary sidewalls. Also a vertical treatment shall be applied around the completed structure, after landscaping and irrigation installation. Disturbance of the treatments will require retreatment of the disturbed area. {Sec. 2304.6.3.5}	Same.
Discharge distance for condensate drain lines, condensing units, roof downspouts, sprinklers	Not specified.	Condensate drain lines, condensing units, roof downspouts shall not place water <2 ft of the structure sidewall. Gutters required on all eaves <12 in horizontal projection. Sprinkler heads shall not apply water <1 ft of structure wall. {Sec. 2304.6.3.6}	No water <2 ft from structure wall. Gutters on eaves <16 in horizontal projection.

Table 3-1 continued.

Subject	Standard Building Code [1]	TPO [2], April 28, 1996	TPO [3], July 22, 1998
Pre-construction soil chemical treatment notice	Not specified.	Weather-tight and obvious treatment certificate (for each treatment) posted on jobsite, copies provided for building permit holder and building permit file. {Sec. 2304.6.4.1}	Same.
Homeowner notification of pre-construction soil chemical treatment company, contact information, and necessity for reinspection	Not specified.	Permanent sign of at least 3x5 in posted in a conspicuous place in the garage or within 3 ft of the electric panel box. Exterior signs must be weatherproof. {Sec. 2304.6.4.2}	Same.
Preconstruction soil chemical treatment warranty and renewal	Not specified.	Occupant or title holder shall receive an unlimited 1 yr retreatment and repair warranty with an optional 4 yr renewal provision. {Sec. 2304.6.4.3}	Same.

1. Termite-protection related sections adapted from the 1994 Edition of the Standard Building Code by Southern Building Code Congress International, Inc. (SBCCI 1994).
2. Adapted from the Termite Protection Ordinance appended to the 1994 Edition of the Standard Building Code by Southern Building Code Congress International, Inc. (SBCCI 1994).
3. Adapted from the Termite Protection Ordinance appended to the 1997 Edition of the Standard Building Code by Southern Building Code Congress International, Inc. (SBCCI 1997).

Table 3-2. Response and infestation rates of houses classified by political boundary, age, and St. Johns County Building Code

Classification	N Delivered [1]	% Response [2]	*P* Response	% Infested [3]	*P* Infested
Political Boundary					
Flagler County	4541	18.21	< 0.0001 [4]	2.70	< 0.0001 [5]
Jacksonville Beach	513	19.49		17.60	
St. Johns County	6973	22.36		15.85	
Average of all houses	12027	20.67		11.60	
Age of House [6]					
2 years (built in 1998)	2603	22.59	0.0070 [7]	2.14	< 0.0001 [8]
3 years (built in 1997)	2453	21.73		4.70	
4 years (built in 1996)	2459	20.13		12.43	
5 years (built in 1995)	2270	19.82		17.87	
6 years (built in 1994)	2242	18.73		25.68	
Average of all houses	12027	20.67		11.60	
St. Johns County Building Code [9]					
Old	2981	22.81	0.4322 [10]	27.79	< 0.0001 [11]
New	3992	22.02		7.10	
Average for all houses	6973	22.36		15.85	

1. Number of surveys delivered. Surveys were consider to be delivered if they were not returned (unopened) as undeliverable by the postmaster.
2. Percentage of voluntarily returned surveys only.
3. Homeowners who answered "don't know" to infestation status were considered to have no evidence of infestation and included in the "no" category. Percentage includes both voluntarily returned and phone surveys.
4. *P*- value for chi-square test (X^2=29.2787, df=2).
5. *P*- value for chi-square test (X^2=98.5207, df=2).
6. True construction year based on building permit numbers.
7. *P*- value for chi-square test (X^2=14.0807, df=4).
8. *P*- value for chi-square test (X^2=182.1942, df=4).
9. Old = houses built 01 Jan 1994 - 27 Apr 1996. New = houses built 28 Apr 1996 - 31 Dec 1998.
10. *P*- value for chi-square test (X^2=0.6168, df=1).
11. *P*- value for chi-square test (X^2=126.0174, df=1).

Table 3-3. Infestation rates of houses classified by pre-construction soil chemical treatment type.

Classification or Survey Response	N	% Infested [1]	*P*
Pre-construction chemical classification [2]			
Repellent	686	15.89	< 0.0001 [3]
Nonrepellent	700	9.00	
Average for all houses	1386	12.41	
Repellent chemical treatments (no. of pest control companies)			
Bifenthrin (1)	1	0.00	< 0.0001 [4]
Cypermethrin (15)	546	12.82	
Fenvalerate (1)	9	44.44	
Permethrin (3)	130	26.92	
Average for all houses (20)	686	15.89	
Nonrepellent chemical treatments (no. of pest control companies)			
Chlorpyrifos (9)	674	9.20	0.7434 [4]
Fipronil (1)	1	0.00	
Imidacloprid (4)	25	4.00	
Average for all houses (13)	700	9.00	

1. Homeowners who answered "don't know" to infestation status were considered to have no evidence of infestation and included in the "no" category.
2. Vertical pre-construction treatment soil chemical information obtained from pest control companies and county building records.
3. *P*- value for chi-square test (X^2=14.9706, df=1).
4. *P*-value for Fisher's exact test. Fisher's exact test is performed when the conditions for a chi-square test are not met. It is especially appropriate for tables with expected cell frequencies ≤ 5 (Schlotzhauer and Littell 1997).

Table 3-4. Infestation rates of houses among survey responses to construction types and maintenance-related questions

Survey Response	N	% Infested [1]	X^2, df	P
Foundation Type				
Above-ground basement	3	0.00	----	1.0000 [2]
Concrete slab	2531	11.66		
Combination concrete slab and crawl space	3	0.00		
Crawl space	43	11.63		
Total	2580	11.63		
Wall Construction				
Logs	2	0.00	----	< 0.0001 [2]
Concrete block	1172	3.84		
Steel	22	0.00		
Wood	1379	18.49		
Total	2575	11.65		
Exterior Cladding Type				
Brick	310	15.16	----	< 0.0001 [2]
Brick and siding	39	15.38		
Brick and stucco	49	10.20		
Siding	379	10.03		
Siding and stucco	85	23.53		
Stucco	1717	10.72		
Total	2579	10.07		
4 - 6" inspection gap				
Yes	847	10.98	1.0884, 1	0.3391
No	1611	12.41		
Total	2458	11.96		
Sprinklers wet house				
Yes	838	13.72	5.1267, 1	0.0236
No	1672	10.65		
Total	2510	11.67		

Table 3-4 Continued

Survey Response	N	% Infested	X^2, df	P
Gutters				
Full	1343	12.29	2.8793, 1	0.2370
Partial	222	13.51		
None	994	10.36		
Total	2559	11.65		
Air conditioner condensation drip line				
Yes	1280	12.81	3.5217, 1	0.0606
No	1302	10.45		
Total	2582	11.62		
Gutter downspout				
Yes	1047	14.90	18.4601, 1	< 0.0001
No	1535	9.38		
Total	2582	11.62		
Access to inspect bathroom plumbing				
Yes	486	13.79	2.7401, 1	0.0979
No	1569	11.03		
Total	2055	11.68		
Sprinkler heads, irrigation or lighting lines				
Yes	1508	12.33	1.8065, 1	0.1789
No	1074	10.61		
Total	2582	11.62		
Mulch				
Yes	1861	11.87	0.4268, 1	0.5136
No	721	10.96		
Total	2582	11.62		
Wooden fence post				
Yes	292	11.99	0.0444, 1	0.8332
No	2291	11.57		
Total	2583	11.61		

Table 3-4 Continued

Survey Response	N	% Infested [1]	X^2, df	P
Firewood				
Yes	42	4.76	------	0.2236 [2]
No	2542	11.72		
Total	2584	11.61		
Trees, shrubs, stumps				
Yes	1742	12.63	5.4573, 1	0.0195
No	843	9.49		
Total	2585	11.61		

1. Homeowners who answered "don't know" to infestation status were considered to have no evidence of infestation and included in the "no" category.
2. *P*-value for Fisher's exact test. Fisher's exact test is performed when the conditions for a chi-square test are not met. It is especially appropriate for tables with expected cell frequencies ≤ 5 (Schlotzhauer and Littell 1997).

Table 3-5. Frequencies of foundation, wall, and exterior cladding types classified by political boundary

	Frequency for political boundary (% [1])				
	Total (% [1])	Flagler County	St. Johns County	Jacksonville Beach	P [2]
Foundation Type					
Above-ground basement	3 (0.12)	2 (0.24)	1 (0.06)	0	0.0244
Crawl Space	43 (1.67)	5 (0.59)	35 (2.18)	3 (2.48)	
Concrete Slab	2531 (98.10)	843 (99.06)	1570 (97.64)	118 (97.52)	
Combination crawl space and concrete	3 (0.12)	1 (0.12)	2 (0.12)	0	
slab	2580	851	1608	121	
Total number of homeowners who answered					
Wall Construction	2 (0.08)	1 (0.12)	1 (0.06)	0	< 0.0001
Log home	22 (0.85)	2 (0.24)	20 (1.25)	0	
Steel frame	1172 (45.51)	744 (87.53)	423 (26.36)	5 (4.17)	
Concrete block	1379 (53.55)	103 (12.12)	1161 (72.34)	115 (95.83)	
Wood frame	2575	850	1605	120	
Total number of homeowners who answered					
Exterior Cladding Type					
Brick	310 (12.01)	88 (10.33)	214 (13.30)	8 (6.78)	< 0.0001
Brick and siding	39 (1.51)	16 (1.88)	19 (1.18)	4 (3.39)	
Brick and stucco	49 (1.90)	18 (2.11)	29 (1.80)	2 (1.69)	
Siding	379 (14.70)	114 (13.38)	225 (13.98)	40 (33.90)	
Siding and stucco	85 (3.30)	16 (1.88)	49 (3.05)	20 (16.95)	
Stucco	1717 (66.58)	600 (70.42)	1073 (66.69)	44 (37.29)	
Total number of homeowners who answered	2579	852	1609	118	

1. Percentage within column group.
2. P-value for Fisher's exact test. Fisher's exact test is performed when the conditions for a chi-square test are not met. It is especially appropriate for tables with expected cell frequencies ≤ 5 (Schlotzhauer and Littell 1997).

Table 3-6. Frequencies of foundation, wall, and exterior cladding types classified by house age [1]

	Frequency for House Age (Years) (% [2])						
	Total (% [2])	2	3	4	5	6	*P*
Foundation Type							
Above-ground basement	3 (0.12)	0 (0.00)	1 (0.18)	0 (0.00)	0 (0.00)	2 (0.46)	0.0817 [3]
Crawl Space	43 (1.67)	7 (1.15)	6 (1.08)	12 (2.35)	11 (2.35)	7 (1.59)	
Concrete Slab	2531 (98.10)	600 (98.68)	545 (98.55)	499 (97.65)	457 (97.44)	430 (97.95)	
Combination crawl space and concrete slab	3 (0.12)	1 (0.16)	1 (0.18)	0 (0.00)	1 (0.21)	0 (0.00)	
Total number of homeowners who answered	2580	608	553	511	469	439	
Wall Construction							
Log home	2 (0.08)	0 (0.00)	1 (0.18)	1 (0.19)	0 (0.00)	0 (0.00)	<0.0001 [4]
Steel frame	22 (0.85)	4 (0.66)	8 (1.45)	7 (1.37)	2 (0.43)	1 (0.23)	
Concrete block	1172 (45.51)	326 (53.71)	282 (51.18)	220 (42.97)	190 (40.68)	154 (35.16)	
Wood frame	1379 (53.55)	277 (45.63)	260 (47.19)	284 (55.47)	275 (58.89)	283 (64.61)	
Total number of homeowners who answered	2575	607	551	512	467	438	
Exterior Cladding Type							
Brick	310 (12.01)	84 (13.84)	54 (9.82)	55 (10.74)	57 (12.13)	60 (13.64)	0.8193 [5]
Brick and siding	39 (1.51)	9 (1.48)	7 (1.27)	8 (1.56)	6 (1.28)	9 (2.05)	
Brick and stucco	49 (1.90)	13 (2.14)	8 (1.45)	10 (1.95)	7 (1.49)	11 (2.50)	
Siding	379 (14.70)	78 (12.85)	86 (15.64)	75 (14.65)	73 (15.53)	67 (15.22)	
Siding and stucco	85 (3.30)	15 (2.47)	19 (3.46)	20 (3.91)	18 (3.83)	13 (2.95)	
Stucco	1717 (66.58)	405 (67.22)	376 (68.36)	340 (67.19)	313 (65.74)	283 (63.64)	
Total number of homeowners who answered	2579	607	550	512	470	440	

1. True construction year based upon building permit numbers. For houses aged 2 years, construction began in 1998; for houses aged 3 years, construction began in 1997; for houses aged 4 years, construction began in 1996; for houses aged 5 years, construction began in 1995; and, for houses aged 6 years, construction began in 1994.

Table 3-6 Continued

2. Percentage within column group.
3. P-value for chi-square test (X^2=14.0012, df=8).
4. P-value for Fisher's exact test. Fisher's exact test is performed when the conditions for a chi-square test are not met. It is especially appropriate for tables with expected cell frequencies ≤ 5 (Schlotzhauer and Littell 1997).
5. P-value for chi-square test (X^2=14.2173, df=20).

Table 3-7. Frequencies of foundation, wall, and exterior cladding types in St. Johns County classified by building code [1]

	Total (% [2])	St. Johns County Building Code (% [2]) Old	New	P
Foundation Type				
Above-ground basement	1 (0.06)	1 (0.15)	0 (0.00)	0.2451 [3]
Crawl Space	35 (2.18)	18 (2.64)	17 (1.84)	
Concrete Slab	1570 (97.64)	661 (96.92)	909 (98.16)	
Combination crawl space and concrete slab	2 (0.12)	2 (0.29)	0 (0.00)	
Total number of homeowners who answered	1608	682	926	
Wall Construction				
Log home	1 (0.06)	1 (0.15)	0 (0.00)	< 0.0001 [3]
Steel frame	20 (1.25)	4 (0.59)	16 (1.73)	
Concrete block	423 (26.36)	129 (18.97)	294 (31.78)	
Wood frame	1161 (72.34)	546 (80.29)	615 (66.49)	
Total number of homeowners who answered	1605	680	925	
Exterior Cladding Type				
Brick	214 (13.30)	97 (14.48)	117 (12.46)	0.8772 [4]
Brick and siding	19 (1.18)	8 (1.19)	11 (1.17)	
Brick and stucco	29 (1.80)	13 (1.94)	16 (1.70)	
Siding	225 (13.98)	89 (13.28)	136 (14.48)	
Siding and stucco	49 (3.05)	20 (2.99)	29 (3.09)	
Stucco	1073 (66.69)	443 (66.12)	630 (67.09)	
Total number of homeowners who answered	1609	670	939	

1. New St. Johns County Building Code went into effect April 27, 1996. Classification by building code is based upon building permit date.
2. Percentage within column group.
3. P-value for Fisher's exact test. Fisher's exact test is performed when the conditions for a chi-square test are not met. It is especially appropriate for tables with expected cell frequencies ≤ 5 (Schlotzhauer and Littell 1997).
4. P-value for chi-square test (X^2=1.7914, df=5).

Table 3-8. Foundation, wall, and exterior cladding frequencies of survey houses classified by preconstruction soil chemical type [1]

		Preconstruction Soil Chemical Type (% [2])			
	Total (% [2])	Repellent [3]	Nonrepellent [4]	X^2, df	P
Foundation Type					
Above-ground basement	0 (0.00)	0 (0.00)	0 (0.00)	1.5672, 1	0.2106
Crawl Space	22 (1.59)	8 (1.17)	14 (2.01)		
Concrete Slab	1359 (98.41)	677 (98.83)	682 (97.99)		
Combination crawl space and concrete slab	0 (0.00)	0 (0.00)	0 (0.00)		
Total number of homeowners who answered	1381	685	696		
Wall Construction					
Log home	0 (0.00)	0 (0.00)	0 (0.00)	20.8938, 1	< 0.0001
Steel frame	13 (0.94)	9 (1.31)	4 (0.58)		
Concrete block	418 (30.33)	170 (24.82)	248 (35.79)		
Wood frame	947 (68.72)	506 (73.87)	441 (63.64)		
Total number of homeowners who answered	1378	685	693		
Exterior Cladding Type					
Brick	187 (13.59)	97 (14.16)	90 (13.02)	17.4143, 1	0.0038
Brick and siding	32 (2.33)	26 (3.80)	6 (0.87)		
Brick and stucco	17 (1.24)	9 (1.31)	8 (1.16)		
Siding	161 (11.70)	75 (10.95)	86 (12.45)		
Siding and stucco	50 (3.63)	31 (4.53)	19 (2.75)		
Stucco	929 (67.51)	448 (65.40)	481 (69.61)		
Total number of homeowners who answered	1376	685	691		

1. Vertical preconstruction chemical soil treatment information obtained from pest control companies and county building records.
2. Percentage within column group.
3. Repellent preconstruction treatments include Demon, Prevail (both cypermethrin), Dragnet (permethrin), and Tribute (fenvalerate).
4. Nonrepellent preconstruction treatments include Dursban (chlorpyrifos) and Premise (imidacloprid).

Table 3-9. Comparison of house characteristics by St. Johns County Building Code

Characteristic	St. Johns County Code [1]	N [2]	% of Houses	X^2, df	P
House has a gutter downspout that discharges within 2 feet of the foundation	Old	449	66.15	1.0198, 1	0.3126
	New	558	63.08		
House has an air conditioner condensation drip line within 2 feet of the foundation	Old	679	55.08	22.9041, 1	0.0001
	New	930	43.01		
House has exterior cladding other than brick and has a 4-6" inspection gap [3]	Old	564	37.59	5.6636, 1	0.0173
	New	783	44.06		

1. Old = houses built 01 Jan 1994 - 27 Apr 1996. New = houses built 28 Apr 1996 - 31 Dec 1998.
2. Refers to the number of houses that either have a gutter downspout, an air conditioner condensation drip line, or cladding other than brick.
3. The new St. Johns County Building Code did not require an inspection gap around houses covered by brick veneer. Only St. Johns County houses covered by cladding other than brick are included in this analysis.

Table 3-10. Frequencies of types and locations of subterranean termite evidence found in association with 300 infested houses [1]

Area of House	Frequency (% [2])			Total (% [2])	P [3]
	Alates	Damage	Mud Tubes		
Door Frame /Adjacent Slab	59 (15.28)	55 (19.30)	20 (14.60)	134 (16.58)	0.0238
Bathroom	29 (7.51)	20 (7.02)	6 (4.38)	55 (6.81)	
Eaves/ Attic/ Roof	10 (2.59)	8 (2.81)	6 (4.38)	24 (2.97)	
Window - outside house	25 (6.48)	25 (8.77)	11 (8.03)	61 (7.55)	
Window - inside house	100 (25.91)	54 (18.95)	21 (15.33)	189 (23.39)	
Fireplace	2 (0.52)	2 (0.70)	0 (0.00)	4 (0.50)	
Foundation / Siding	48 (12.44)	25 (8.77)	35 (25.55)	108 (13.37)	
Door Frame - inside house	33 (8.55)	24 (8.42)	9 (6.57)	66 (8.17)	
Wall - inside house	66 (17.10)	54 (18.95)	21 (15.33)	141 (17.45)	
Kitchen	14 (3.63)	10 (3.51)	2 (1.46)	26 (3.22)	
Total	386 (47.77)	285 (35.27)	137 (16.96)	808 (100.00)	

1. Homeowner may have indicated more than one type of evidence and more than one infested area of house.
2. Percentage within column group.
3. P-value for chi-square test (X^2=31.7059, df=18).

Table 3-11. Awareness of pre-construction pest control company and contract renewal

	N [1]	%	X^2, df	P
Homeowners knew which pest control company treated house at time of construction	2580	88.53	—	---
Termite contract was still in effect. Homeowners paid annual renewal fee.	2284	82.23	—	---
By Age of House: homeowners knew which pest control company treated house at time of construction				
2 years (built in 1998)	608	92.76	30.5379, 4	< 0.0001
3 years (built in 1997)	553	90.96		
4 years (built in 1996)	513	88.50		
5 years (built in 1995)	468	84.19		
6 years (built in 1994)	438	84.25		
By Political Boundary: homeowners knew which pest control company treated house at time of construction				
Flagler County	855	86.55	6.0960, 2	0.0475
St. Johns County	1607	89.73		
Jacksonville Beach	118	86.44		

1. Number of people who answered the question.

Table 3-12. Comparison between voluntarily returned mail-out surveys and phone surveys for houses classified by political boundary, age, and construction types

Classification	N (Mail) [1]	% Mail	N (Phone) [2]	% Phone	X^2, df	P
Political Boundary [3]						
Flagler County	827	33.27	25	25.00	92.0082, 2	0.0001
Jacksonville Beach	100	4.02	25	25.00		
St. Johns County	1559	62.71	50	50.00		
Total	2486	100.00	100	100.00		
Age of House [4]						
2 years (built in 1998)	586	23.57	22	22.00	4.4966, 4	0.3430
3 years (built in 1997)	537	21.60	16	16.00		
4 years (built in 1996)	495	19.91	20	20.00		
5 years (built in 1995)	452	18.18	18	18.00		
6 years (built in 1994)	416	16.73	24	24.00		
Total	2486	100.00	100	100.00		
Foundation Type						
Above-ground basement	3	0.12	0	0.00	—	<0.0001 [5]
Concrete slab	2449	98.51	82	82.00		
Combination concrete slab and crawl space	3	0.12	0	0.00		
Crawl space	25	1.01	18	18.00		
Total	2480	100.00	100	100.00		
Wall Construction						0.4999 [5]
Logs	2	0.08	0	0.00	---	
Concrete block	1133	45.58	39	39.00		
Steel	22	0.89	0	0.00		
Wood	1318	53.02	61	61.00		
Total	2475	100.00	100	100.00		

Table 3-12 Continued

Classification	N (Mail) [1]	% Mail	N (Phone) [2]	% Phone	X^2, df	P
Exterior Cladding Type						
Brick	306	12.31	4	4.00	---	< 0.0001 [5]
Brick and siding	37	1.49	2	2.00		
Brick and stucco	48	1.93	1	1.00		
Siding	368	14.81	11	11.00		
Siding and stucco	58	2.33	27	27.00		
Stucco	1662	66.85	55	55.00		
Total	2479	100.00	100	100.00		

1. Number of voluntarily returned surveys.
2. Total number of phone surveys.
3. Phone survey counts among political boundaries were predetermined.
4. True construction year based upon building permit numbers.
5. P-value for Fisher's exact test. Fisher's exact test is performed when the conditions for a chi-square test are not met. It is especially appropriate for tables with expected cell frequencies ≤ 5 (Schlotzhauer and Littell 1997).

Table 3-13. Survey answer comparisons between homeowners who returned the mailed survey and homeowners who were surveyed by phone

Survey Answer	Survey Type	N	% of homeowner responses Yes	No	Don't Know	X^2, df	*P*
House has a 4-6" inspection gap	Mail	2481	32.81	62.47	4.72	0.3672, 2	0.8323
	Phone	100	33.00	61.00	6.00		
	Total	2581	32.82	62.42	4.66		
House has access to inspect bathroom plumbing	Mail	2478	19.13	60.49	20.38	4.2867, 2	0.1173
	Phone	100	12.00	70.00	18.00		
	Total	2578	18.85	60.86	20.29		
Sprinklers wet wall(s) of house	Mail	2484	32.37	64.69	2.94	----	0.6399 [1]
	Phone	100	34.00	65.00	1.00		
	Total	2584	32.43	64.71	2.86		
House has an air conditioner condensation line which discharges < 2 ft from foundation	Mail	2483	49.13	50.83	0.04	----	0.0780 [1]
	Phone	100	60.00	40.00	0.00		
	Total	2583	49.55	50.41	0.04		
House has a gutter downspout which discharges < 2 ft from foundation	Mail	2482	40.25	59.75	0.00	2.3951, 1	0.1217
	Phone	100	48.00	52.00	0.00		
	Total	2582	40.55	59.45	0.00		
House has a sprinkler head, irrigation or lighting lines < 2 ft from foundation	Mail	2482	58.34	41.66	0.00	0.1090, 1	0.7413
	Phone	100	60.00	40.00	0.00		
	Total	2582	58.40	41.60	0.00		
House has mulch < 2 ft from foundation	Mail	2482	72.92	27.96	0.00	0.0049, 1	0.9444
	Phone	100	73.00	27.00	0.00		
	Total	2582	72.08	27.92	0.00		
House has a wooden fence post < 2 ft from foundation	Mail	2483	11.07	88.96	0.00	3.4214, 1	0.0644
	Phone	100	17.00	83.00	0.00		
	Total	2583	11.30	88.70	0.00		
House has firewood < 2 ft from foundation	Mail	2484	1.53	98.47	0.00	----	0.0769 [1]
	Phone	100	4.00	96.00	0.00		
	Total	2584	1.63	98.37	0.00		

Table 3-13 Continued

Survey Answer	Survey Type	N	% of Homeowner Responses: Yes	No	Don't Know	X^2, df	P
House has trees, shrubs or stumps < 2 ft from foundation	Mail	2485	66.84	33.16	0.00	8.7695, 1	0.0031
	Phone	100	81.00	19.00	0.00		
	Total	2585	67.39	32.61	0.00		
Homeowners know what pest control company applied pre-construction soil treatment	Mail	2478	89.18	10.82	0.00	0.0034, 1	0.9535
	Phone	100	89.00	11.00	0.00		
	Total	2578	89.18	10.82	0.00		
Homeowners renewed contract with the pest control company that applied their pre-construction soil treatment	Mail	2210	81.54	16.92	1.54	----	0.0014 [1]
	Phone	89	95.51	4.49	0.00		
	Total	2299	82.08	16.44	1.48		
Homeowner has seen evidence of subterranean termites	Mail	2422	11.65	86.04	2.31	----	0.0643 [1]
	Phone	100	18.00	82.00	0.00		
	Total	2522	11.90	85.88	2.22		
Curative treatment by a pest control company	Mail	282	98.23	1.77	0.00	----	1.0000 [1]
	Phone	18	100.00	0.00	0.00		
	Total	300	98.33	1.67	0.00		
House has gutters [2]	Mail	2483	60.89	38.14	0.97	----	0.1769 [1]
	Phone	100	53.00	47.00	0.00		
	Total	2583	60.59	38.48	0.93		

1. *P*-value for Fisher's exact test. Fisher's exact test is performed when the conditions for a chi-square test are not met. It is especially appropriate for tables with expected cell frequencies ≤ 5 (Schlotzhauer and Littell 1997).
2. Houses for which homeowners indicated "Full" and "Partial" gutters were combined for analysis into the "Yes" category. (For mailed surveys: full 52.28%, partial 8.62%, none 38.14%, don't know 0.97%. For phone surveys: full 45.00%, partial 8.00%, none 47.00%. Total: full 51.99%, partial 8.59%, none 38.48% don't' know 0.93%. Fisher's exact test *P*-value: 0.3393.)

Table 3-14. Percentage agreement between site inspections of 35 houses and answers to questions on voluntarily returned mail survey for each respective house

Physical Attribute	%
Foundation type	100
Exterior wall construction	100
Exterior cladding type	100
Firewood < 2 ft from foundation	100
Gutters	94.29
Wooden fence post < 2 ft from foundation	91.43
Mulch < 2 ft from foundation	88.57
Sprinkler head, irrigation or lighting lines < 2 ft from foundation	85.71
Sprinklers wet house	82.86
Gutter downspout discharge < 2 ft from foundation	82.86
4-6 inch inspection gap	77.14
Air conditioner condensation drip line discharge < 2 ft from foundation	77.14
Live trees, stumps, or shrubs < 2 ft from foundation	77.14
Access to inspect bathroom plumbing	20.00
Mean % correctly answered questions	84.08

1. When was construction on your home started?

_____ 1994 ____ 1995 ____ 1996 ____ 1997 ____ 1998

2. Which best describes your house? (Please chose **one** answer from **each** column -- A, B, and C.)

A) Foundation:	B) Walls:	C) Exterior Wall Finish:
_____ Concrete slab	_____ Concrete block	_____ Brick, stone, concrete block
_____ Crawl space	_____ Wood frame	_____ Stucco
_____ Basement	_____ Steel frame	_____ Vinyl or aluminum siding
Other: _____________	Other: ______________	_____ Wood siding
		Other: _________________

3. Can you see 4 to 6 inches of concrete foundation around the bottom of your home, with no stucco, brick, or other siding covering the concrete? _______ Yes _______ No ______ Don't know

4. Does your house have an access to inspect bathroom plumbing (access port may be in the bathroom, adjoining hallway, closet, etc.)? ______ Yes ______ No ______ Don't know

5. Does water from either your or your neighbor's sprinklers hit/wet the side of your house?

_______ Yes _______ No ______ Don't know

6. Does your house have gutters? _______ No _______ Full ______ Partial ______ Don't know

7. Does your house have any of these within 2 feet of the foundation? (Please check all that apply.)

_____ Condensation lines from the air conditioner
_____ Downspouts
_____ Sprinkler heads, irrigation lines, lighting lines
_____ Mulch (organic or inorganic)
_____ Wooden fence posts
_____ Firewood (storage)
_____ Live trees, shrubbery, tree stumps

Figure 3-1. Survey mailed to single-family homeowners.

8. Do you know which pest control company treated your home for subterranean termite control at the time of construction?
_______ Yes _______ No

If "Yes", is the termite control contract with the pest control company that treated your home at the time of construction still in effect (e.g. this normally requires paying the pest control company an annual fee to renew the contract)? _____ Yes _____ No _____ Don't know

9. Has your home ever been infested with subterranean termites? ____ Yes ____ No _____ Don't know

Only answer the remaining questions if your home has been infested with subterranean termites.

10. In what month and year was the termite infestation first discovered?
Month _________ Year ________

11. What were the signs of infestation? (Please check all that apply.)
____ don't know (happened when previous owner lived here)
____ damage ____ winged termites ____ mud tubes ____ other:________________________

12. Please check all the areas below where signs of termite infestation have been found in or around your home:

Interior	Exterior
_____ Baseboards	_____ Attic/roof
_____ Door frame	_____ Door frame (exterior door)
_____ Window frame/sill	_____ Garage door frame
_____ Near bathroom plumbing	_____ Siding / cladding
_____ Near kitchen plumbing	_____ Foundation
_____ Attic	_____ Window frame
	_____ Eaves/soffits

Other: ____

Figure 3-1 continued.

13. Was the termite infestation treated by a pest control company? _____ Yes _____ No

If "Yes", what was the name of the company that treated the infestation? ______________________________

What was the approximate cost of treatment? ______________________

Is treatment warranty still maintained on your house from this treatment? _____ Yes _____ No

If "No" (the infestation was not treated by a pest control company), what did you do about the termite infestation?

____

____

14. What was the approximate cost of repairs? ______________

Figure 3-1 continued.

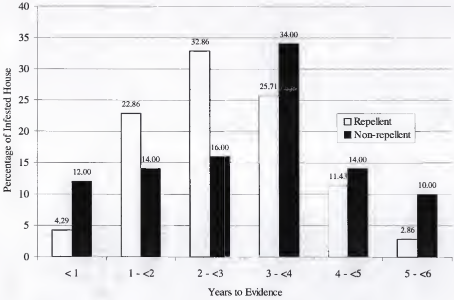

Figure 3-2. Percentage of houses infested by amount of time (years) from start of home construction until evidence of subterranean termite infestation, classified by pre-construction soil chemical type. Repellent pre-construction treatments (n=70) include Demon, Prevail (both cypermethrin), Dragnet (permethrin), and Tribute (fenvalerate). Non-repellent pre-construction treatments (n=50) include Dursban (chlorpyrifos) and Premise (imidacloprid). See Table 3-3 for chemical frequencies and infestation rates. *P* - value for Fisher's exact test: 0.0716.

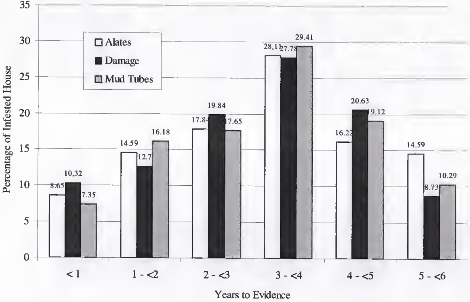

Figure 3-3. Percentage of homes with evidence of subterranean termite infestation by amount of time (years) from start of house construction until evidence of subterranean termite infestation, classified by type of evidence. N = 300 infested houses. Homeowners may have indicated more than one type of evidence for house. (X^2=4.3037, df=10, P= 0.9326)

CHAPTER 4
RESULTS FROM SITE INSPECTIONS OF 35 SUBTERRANEAN TERMITE INFESTED HOMES IN ST. JOHNS COUNTY, FL

Introduction

Subterranean termites construct systematic foraging galleries in laboratory arenas (Robson et al. 1995, Reinhard et al. 1997, Puche and Su 2001). In the field, termite foraging is influenced by soil temperature (Ettershank et al. 1980, Rust et al. 1996, Houseman et al. 2001), soil moisture (Houseman et al. 2001), and topographic features such as guidelines that may be formed by root systems or the edge of structural foundations (Jander and Daumer 1974, Campora and Grace 2001). In spite of what is known about subterranean termite foraging, researchers are still not able to predict termite foraging behavior with certainty.

In order to protect structures from subterranean termites, homeowners have traditionally relied on pest management professionals to apply soil termiticides or install bait systems. However, researchers have known since the early 1900's that subterranean termite structural damage may be inhibited by decreasing the hospitality of the structural environment (Snyder 1948). Soil temperature is an uncontrollable factor, as Florida subterranean termites may forage year-round due to the state's mild climate. However, other factors conducive to termite survival, such as available cellulose, guidelines, and soil moisture, can be limited through enforcement of reasonable building codes (Brown et al. 1934).

One Florida county, St. Johns, attempted to reduce subterranean termite infestations in homes by enactment of a Termite Protection Ordinance amended to the building code, effective April 28, 1996. The Ordinance was expected to reduce wood–to–ground contact, eliminate hidden termite access into structures, and limit soil moisture (Table 3-1).

The objectives of this chapter were to identify features common to subterranean termite-infested locations and their surrounding areas with respect to St. Johns County houses and to determine if the newer houses met certain requirements of the Ordinance.

Materials and Methods

Site Inspection Population

Site inspections were conducted for 35 infested premises belonging to homeowners in St. Johns County who answered a mailed survey in 2000 (Chapter 3). Infested houses were identified by respondent homeowners and only houses built in 1995 and 1997 were included. Houses built in 1995 represented those built before the Termite Protection Ordinance and houses built in 1997 represented those built under the Ordinance after it was enacted. Homeowners of infested houses were contacted by telephone in order to establish inspection appointment times. Inspections were conducted July through August 2001.

Site Inspection Data

Construction information documented for each house consisted of linear foundation size, foundation type, wall construction, exterior cladding type, number of roof faces, and width of eaves. Data were collected for each area of interest (AOI) for infested houses. An AOI was defined as a 3.05 m (10 ft) radius around an area of the

house identified by the homeowner as having been infested by subterranean termites. The linear center of the AOI was the actual site of termite evidence and the remainder of the AOI continued for 1.53 m (5 ft) to the left and right of center. The number of AOIs for each house was determined by consulting the homeowner. For each AOI, measurements were taken on the outside of the house regarding distances of foundations to shrubs, to gutter downspout discharge, to air conditioner condensation drip line discharge, and to the nearest sprinkler head. At the AOI and along the slab perimeter, the height of the inspection space, if any, from cladding to soil and mulch were measured. Distances above soil for door and window sills within the AOI were measured.

Moisture readings were taken at walls associated with AOI on both the interior and exterior sides. Readings were detected using a padded Tramex Moisture Encounter (Tramex Limited, Dublin, Ireland). The padded device was moved in a zig-zag pattern between the bottom of the wall and 1.83 m (6 ft) above the bottom along 1.53 linear m (5 linear ft) of a wall in either direction radiating from the area of subterranean termite evidence. Two moisture readings, a minimum and maximum, were noted for each AOI.

The pH of soil adjacent to AOI was determined on site using a hand-held pH meter (pH Pro, Spectrum Technologies, Inc., Plainfield, IL; accuracy: ±0.2 pH). Twenty-five mL of soil was collected from within 15 cm of the exterior wall closest to the AOI. Fifty mL of distilled water was mixed with the soil. The meter probe was lowered into the water after the mixture settled. One reading was taken at each AOI that encompassed soil.

Analysis

Means, minimums and maximums for foundation size, eave length, number of roof faces, soil pH, number of AOI per house, interior and exterior wall moisture,

distance of foundation to shrubs, length of inspection space above soil, and distance of door and window sills above soil were summarized.

Houses built in 1995 and 1997 were compared with respect to characteristics affected by the St. Johns County Termite Protection Ordinance and the number of areas of interest per house. For these houses, mean measurements of foundation to downspout discharge, foundation to air conditioner condensation drip line discharge, foundation to nearest sprinkler head, inspection space distance above mulch, and mean number of areas of interest were compared by the Wilcoxon Rank Sum test (SAS Institute 2000) using a 10% significance level.

The Wilcoxon Rank Sum test was performed in lieu of parametric analysis of variance because the population was not normally distributed and did not have equal variances (Schlotzhauer and Littell 1997).

Results

Thirty-five houses were inspected: 28 were built in 1995 and seven were built in 1997. At the 35 houses, there were 48 AOI: 41 occurred in houses built in 1995 and seven occurred in houses built in 1997. Forty-six AOI were associated with an external load-bearing wall. Two AOI were on the interior of the houses and were not associated with a exterior load-bearing wall.

Characteristics of inspected houses are shown in Table 4-1. Houses averaged 1.37 AOI per house. Interior wall moisture at AOI ranged from 8 to 90%, and exterior wall moisture ranged from 12 to 100%. Houses had a mean of 0.71 cm foundation perimeter inspection space above soil. Only eight AOI were associated with door frames, which

were an average of 9.86 cm above soil. Thirty-four AOI were associated with window sills and averaged 81.20 cm above soil.

Mean distances of foundations to air conditioner condensation drip lines and inspection spaces above mulch were significantly less in houses built in 1995 versus 1997 (Table 4-2). No houses built in 1997 met the Ordinance requirements for any measurements; gutter downspout and condensate lines were mandated to discharge at least 60.96 cm (2 ft) away from the foundation, but 1997 houses discharged water 46.00 and 12.40 cm away, respectively; sprinkler heads were not to apply water within 30.48 cm (1 ft) of the foundation wall, but 1997 houses had sprinkler heads 10.71 cm away (however, water may have been directed beyond the distance mandated by the Ordinance); foundation perimeters were to have a minimum of 15.24 cm (6 in) free of exterior cladding, but the 1997 houses only had 1.29 cm of space. Houses built in 1995 had significantly more AOl, 1.46 ± 0.14 per house, than the seven 1997 houses which each had one per house (Wilcoxon rank sum test standard score = -1.8010, P=0.0717).

Discussion

Results from site inspection indicated that most inspected houses had a monolithic foundation, a wood frame, and stucco exterior cladding. The typical site identified by homeowners as showing evidence of subterranean termites was had adjacent soil pH in the neutral range, and was associated with eaves 39.47 cm (15.54 in) in projection, shrubbery 39.52 cm (15.56 in) from the foundation, an inspection space 0.71 cm (0.28 in) above soil, a door or window sill 9.86 cm (3.88 in) from the soil, mean interior wall moisture ranging from 28.00 to 35.80%, and mean exterior wall moisture ranging from 37.63 to 43.23%.

Areas conducive to subterranean termite foraging have already been identified as moisture prone and having readily available termite food, such as air conditioner slabs, downspout discharge areas, mulch beds, and tree stumps. Soil moisture was reported to be more important than ventilation, humidity, or wood debris in leading to subterranean termite infestation of buildings (Snyder 1948). Henderson et al. (1998a) reported that stakes placed in these conducive areas around structures were attacked twice as often as stakes placed in a fixed pattern. The air conditioner condensation drip lines (Haagsma and Rust 1995) and mulch beds (Fraedrich and Ham 1982, Smith and Rakow 1992) associated with inspected houses served as direct moisture sources for termites. Shrubbery may have also contributed to moisture due to directed irrigation.

Contractors and homeowners of houses built in 1997 did not adhere to the St. Johns County Termite Protection Ordinance for the four factors measured during site inspections: foundation to downspout discharge distance, foundation to air conditioner condensate line discharge distance, foundation to nearest sprinkler head distance, and inspection space above mulch. Results indicated significantly fewer areas of interest in the 1997 houses versus those built in 1995, but this may have been an artifact of small sample size (I only inspected seven houses from 1997).

Table 4-1. Characteristics measured during site inspection of 35 infested St. Johns County, Florida, houses

Characteristic	No. Houses	No. AOI [1]	Mean ± SEM	Min - Max
Foundation size (linear meters)	35	48	79.46 ± 2.84 [2]	55.47 - 140.21 [2]
Length of eaves (centimeters)	35	48	39.47 ± 2.16 [2]	20.32 - 78.74 [2]
Number of roof faces	35	48	17.83 ± 1.11 [2]	9.00 - 32.00 [2]
Soil pH	35	46	6.71 ± 0.09 [2]	5.60 - 8.10 [2]
Number of areas of interest [1]	35	48	1.37 ± 0.12 [2]	1.00 - 4.00 [2]
Minimum interior wall % moisture	33	40	28.00 ± 3.62 [3]	8.00 - 80.00 [3]
Maximum interior wall % moisture	33	41	35.80 ± 4.18 [3]	10.00 - 90.00 [3]
Minimum exterior wall % moisture	32	40	37.63 ± 4.02 [3]	12.00 - 80.00 [3]
Maximum exterior wall % moisture	32	40	43.23 ± 4.21 [3]	14.00 - 100.00 [3]
Foundation to shrubs (centimeters)	35	45	39.52 ± 4.17 [3]	5.08 - 106.68 [3]
Inspection space above soil (centimeters)	35	48	0.71 ± 0.41 [3]	0.00 - 15.24 [3]
Door sill above soil (centimeters)	8	8	9.86 ± 2.31 [3]	0.00 - 17.78 [3]
Window sill above soil (centimeters)	33	34	81.20 ± 5.64 [3]	38.10 - 149.86 [3]

1. AOI = areas of interest = number of areas where subterranean termite evidence was reported by homeowner.
2. Mean, minimum, and maximum for houses.
3. Mean, minimum, and maximum for AOI.

Table 4-2. Comparison of characteristics affected by the St. Johns County Termite Protection Ordinance that were measured within a 3.05 m (10 ft.) radius of structural areas where evidence of subterranean termite infestations were identified by homeowners (areas of interest) in 35 St. Johns County, Florida, houses built in 1995 and 1997

	Mean ± SEM					
Distance (centimeters)	n [1]	1995	n [1]	1997	Standard Score [2]	P [2]
Foundation to downspout discharge	20	29.10 ± 6.22	2	46.00 ± 4.00	1.3149	0.1886
Foundation to A/C drip line	11	2.82 ± 1.00	5	12.40 ± 5.18	2.3051	0.0212
Foundation to nearest sprinkler head	31	12.19 ± 1.18	7	10.71 ± 3.09	-0.0953	0.9241
Inspection space above mulch	41	0.00 ± 0.00	7	1.29 ± 0.71	4.2472	<0.0001

1. Areas of interest = number of areas where subterranean termite evidence was reported by homeowner.
2. Wilcoxon rank sum test (SAS Institute 2000).

CHAPTER 5
RISK ASSESSMENT OF CONSTRUCTION AND MAINTENANCE PRACTICES TO PREDICT SUBTERRANEAN TERMITE INFESTATIONS

Introduction

The total annual economic impact of subterranean termites in the United States has been estimated at $11 billion, with approximately 20% attributed to control by liquid termiticides (Su 2002). Termite control includes both preconstruction and remedial treatments. While costs associated with preconstruction soil termiticide treatments have not been published, treatment failures seem to occur frequently. For example, Kentucky and Ohio soil termiticide treatments from 1995 through 1998 failed in 21.8% of houses treated with either chlorpyrifos or a pyrethroid (Potter 2000). Also, 11.6% of the preconstruction soil termiticide treatments had failed around houses 2 to 6 years old in northeastern Florida (St. Johns County, Flagler County, and Jacksonville Beach; Table 3-2).

Preconstruction soil treatment failure rates differed among political boundaries within northeastern Florida (Chapter 3, Table 3-2). Failure rates in St. Johns County and Jacksonville Beach were 15.85 and 17.60%, respectively, while Flagler County preconstruction treatments failed in only 2.70% of the houses. This was surprising given that the three areas have similar climates and physical environments (Readle et al. 1983, Readle et al. 1997, Watts et al. 1998). One reason for the difference could have been termite pressure. Another explanation could center around construction factors. Flagler

County has less developed land areas and not as many registered builders compared with St. Johns County and Jacksonville Beach. Builders overlap in St. Johns County and Jacksonville Beach, but there is a different group building in Flagler County (pers. Comm., H. T. White, Deputy Chief Building Inspector, St. Johns County, Florida). Presumably, different builders used different building materials and techniques. Additionally, inspection criteria probably differed among the political boundaries.

In order to determine the relationship between political boundary and factors known to be conducive to subterranean termite activity, the data collected from a survey (described in Chapter 3) to develop a structural risk assessment model for houses built in St. Johns County, Jacksonville Beach, and Flagler County from 1994 through 1998.

Materials and Methods

Model Population and Data Collection

All data were collected from the survey described in Chapter 3. Houses for which the preconstruction treatment chemical were known were included in the model. Among political boundaries, 98 Flagler County, 48 Jacksonville Beach, and 1,240 St. Johns County houses were included.

Data Analysis

Model. Answers to survey questions were coded and analyses were performed using SAS (SAS Institute 2000). All houses were labeled as either a control or a case. Controls were each coded by a 0 for never having had a known subterranean termite infestation. Cases were each coded by a 1 if respondents indicated they had seen evidence of subterranean termites in the structure. Answers to other questions were coded 0 if the characteristic did not occur or 1 if the characteristic occurred, according to respondents.

Homeowners who answered "don't know" to the infestation question were included in the not infested group. Other questions left unanswered or answered by "don't know" were not used in the analysis. For analysis, the dependent variable was house infestation status, while the other survey questions, along with preconstruction treatment chemical type, were the independent variables and represented subterranean termite infestation risk factors.

Risk factors were combined into six categories to simplify the model (Table 5-1). St. Johns County and Jacksonville Beach were combined into a single political boundary category because their infestation rates were significantly higher than that of Flagler County (Chapter 3, Table 3-2). (N= 1,386; St. Johns County + Jacksonville Beach infestation rate = 13.12%, Flagler County = 3.06%). Other categories were chosen to reduce biases caused by correlations between variables. Preconstruction soil treatments were identified in Chapter 3. Only houses with complete information were included in the regression analysis, so that 1,331 out of 1,386 were included. House frequencies and proportions of those infested were summarized according to the six categories used for the model: political boundary, structural wood, preconstruction soil treatment chemical type, termite access, non-structural wood, and moisture.

A risk assessment system was developed in which coded variables for each category were subjected to conditional logistic regression to determine the relationship of the coded known risk factors to each other. Approximately 90% of the entire data set was used. Proc Phreg (SAS Institute 2000) was utilized to perform the two-step conditional logistic regression analysis. First, controls and cases were stratified according to year construction began. Secondly, the regression process allowed for analysis of linear combinations of the independent variables to predict likelihood of subterranean termite

infestation. The final model was determined by the backward selection process in which one non-significant ($\alpha = 0.10$) covariate was removed after each regression until only significant covariates remained in the model.

Individual hazard ratios (HR) were converted to probabilities according to the equation: Probability= HR ÷ (HR + 1) (Allison 1991). Probabilities were then scaled so that each represented a fraction of 100 points. This allowed for a percentage infestation likelihood to be determined for each respondent house. Percentages of infested and not infested houses scoring within quartile ranges were compared.

Survey validation. The entire data set (N = 1,331) was divided so that 10% of the respondent houses were randomly chosen to produce a similar proportion of infested houses as occurred in the entire data set. Conditional logistic regression as described above was performed on the remaining 90% data set (model set). Infestation likelihoods were then determined for houses in the 10% set (validation set) based upon regression of the model set. Mean scores of houses from the model set and the validation set were analyzed by Student's t-test ($\alpha = 0.10$).

Results

Data Summary

Most houses included in the model were located in either St. Johns County or Jacksonville Beach (Table 5-2), as opposed to Flagler County. In St. Johns County and Jacksonville Beach, 13.12% of the houses were infested. Only 3.06 % were infested in Flagler County. For the structural wood category, 70.75% of the houses were either slab-on-grade wood frame or concrete block frame with exterior paneling. Of those houses, 15.49% were infested. Only 4.71% of houses without structural wood were infested

(Table 5-2). Preconstruction soil chemical treatment types was almost evenly divided with 687 houses receiving repellent treatments and 699 receiving nonrepellent treatments. Of those houses, 15.87% of the houses treated with a repellent chemical were infested, but only 9.01% of the houses treated with a nonrepellent chemical were infested. For the termite access category, 13.02% of the 1,221 houses that either lacked an inspection space or had some type of termite guideline within 60.96 cm (2 ft) of the foundation were infested. Only 8.55% of the houses without termite access were infested. Most houses did not have non-structural wood within 60.96 cm (2 ft) of the foundation. For those 1,108 houses, 12.73% were infested. For the 278 houses with non-structural wood near the foundation, 11.15% were infested. For the moisture category, 1,253 of the homes with some source of moisture within 60.96 cm (2 ft) of the foundation. 12.53% were infested. Only 84 houses did not have a moisture source near the foundation, and only 9.52% of those were infested.

Model

The non-structural wood and moisture categories were eliminated during the backwards elimination procedure. Significant covariates that remained in order of their contribution to the model were: political boundary > structural wood > repellent preconstruction treatment > termite access (Table 5-3). Among the three areas surveyed, houses in Jacksonville Beach and St. Johns County had an 60% higher probability of being infested than houses in Flagler County (Table 5-3). Slab-on-grade houses with either wood frames or concrete block frames with runners fastened to side paneling were 42% more likely to have subterranean termites than houses without wood near the ground (Table 5-3). Repellent preconstruction soil treatments and termite access both increased

infestation likelihood by 40% over houses with either nonrepellent soil treatments or no termite access (Table 5-3). Infestation likelihood scores ranged from 21.71 to 100 points for non-infested houses and 43.56 to 100 points for infested houses (Fig 5-1). The type I error rate for houses scoring above the median, $\geq$78.15, was 22.16% false positives.

Validation

There were no significant differences between the model and validation data sets for the infested and not infested houses (Table 5-4). Thus, both data sets were similar, indicating that the model data were appropriate for the validation process.

Discussion

Political boundary was the most significant contributor to infestation likelihoods of the houses built between 1994 and 1998 within the surveyed area. This was probably due to a combination of factors including termite pressure, different builders using different building materials, and different inspection criteria among the political boundaries. Termite pressure may have been influenced by historical land use, as Flagler County has a longer history of agricultural land use and Jacksonville Beach / St. Johns County have more housing developments (Readle et al. 1983, Readle et al. 1997, Watts et al. 1998). The surveyed areas also differed in the number of registered builders, as Jacksonville Beach and St. Johns County have 244 single-family home builders (NEFBA 2002), while Flagler County only has 71 (Flagler HBA 2002). Also, for the period 1994 through 1998, the three areas operated under different building codes and inspection criteria.

Structural wood was the second highest contributor to infestation likelihoods, as slab-on-grade houses with either wood frames or concrete block frames with runners

fastened to side paneling were 42% more likely to have subterranean termites. These construction types allow untreated wood to be placed within 20 cm (~8 in) of the soil.

Houses treated with a repellent soil termiticide during the construction process were 40% more likely to have subterranean termites than houses treated with a nonrepellent termiticide according to the results of the regression analysis. This was not surprising as infestation rates among houses treated with either bifenthrin, cypermethrin, fenvalerate, or permethrin were almost double that of houses treated with either chlorpyrifos, imidacloprid, or fipronil (Chapter 3, Table 3-3). Significance of the repellent soil treatments was probably due to variable efficacies, as cypermethrin performed better than permethrin but the nonrepellents performed similarly (Chapter 3, Table 3-3). Variable repellent termiticide performance among the group was reported by Kard et al. (1989), Kard (2000), and Wagner et al. (2003) in Florida USDA-FS field tests. For concrete slab tests, cypermethrin (0.5%) provided 5 years of 100% efficacy, fenvalerate (0.5%) provided 3 years, permethrin (0.5%) provided 6 years, and bifenthrin (0.062%) provided >13 years (Kard et al. 1989, Kard 2000). Nonrepellent termiticides performed consistently, however, as chlorpyrifos (0.5% and 1.0%), imidacloprid (0.05%), and fipronil (0.06%) all provided at least 5 years of 100% protection of wood within concrete slabs (Kard 2000). (These formulations and concentrations reflect the majority of repellent termiticides and concentrations used for vertical preconstruction treatments of respondent houses (see Appendix H)). Compounding the question of efficacy is the problem of even distribution as uniform penetration of any termiticide treatment in soil is unlikely (Kard and McDaniel 1993, Gold et al. 1996). Subterranean termites may then

tunnel through gaps in treated soil (Forschler 1994). Also, termiticide performance could have been influenced by technician error or formulation differences.

Termite access was also responsible for 40% increase in infestation likelihood. Lack of an inspection gap and guidelines provided by roots and electric / irrigation lines were combined into this single category. Without an inspection gap around the entirety of the foundation perimeter, subterranean termites may enter undetected behind cladding or insulation (Guyette 1994, Smith and Zungoli 1995a and b). Also, subterranean termites will readily follow guidelines (Pitts-Singer and Forschler 2000) and exploit cracks in concrete slabs (Lenz et al. 1997). They also tend to circumnavigate the entirety of arenas around the edges (Campora and Grace 2001), which may parallel following the edge of a slab in the field. Therefore, it is not surprising that accessibility adds to infestation likelihood.

Presence of non-structural wood (wooden fence post, firewood, and mulch) within 60.96 cm (2 ft) of the foundation was not a significant contributor to infestation likelihood. In analysis of individual factors, these wood sources also were not significantly associated with infestation rates (Table 3-4).

Areas conducive to subterranean termite foraging have been identified as moisture prone and include air conditioner slabs, downspout discharge areas, and even mulch beds (Fraedrich and Ham 1982, Smith and Rakow 1992, Haagsma and Rust 1995, Henderson et al. 1998a). In fact, soil moisture was found to be more important than ventilation, humidity, or wood debris in leading to subterranean infestation of buildings (Snyder 1948). Therefore, it was unexpected that moisture was not a significant covariate in this model. Non significance of moisture was probably due to sample size, as only 6% of the

houses included in analysis did not have some source of moisture near their foundations.

This subterranean termite risk assessment system is a relative rating system for structural factors conducive to subterranean termite activity. Results must be interpreted with caution, however, because this model is invalid outside of the data collection universe.

Table 5-1. Categories of independent variables for conditional logistic regression

Category	Variables Included
Political boundary	Jacksonville Beach
	St. Johns County
Structural wood	Slab-on-grade wood frame
	Slab-on-grade concrete block frame with exterior paneling
Preconstruction treatment	All repellent soil treatments
Termite access	No inspection gap around the foundation perimeter
	Trees, shrubs, stumps < 60.96 cm (2 ft) from foundation
	Irrigation or lighting lines < 60.96 cm (2 ft) from foundation
Nonstructural Wood	Fence post, firewood, or mulch > 60.96 cm (2 ft) from foundation
Moisture	Air conditioner condensation drip line < 60.96 (2 ft) from foundation
	Gutter downspout < 60.96 cm (2 ft) from foundation
	Sprinkler heads < 60.96 cm (2 ft) from foundation
	Partial or no gutters

Table 5-2. Number of infested houses classified by political boundary, structural wood, preconstruction soil treatment chemical type, termite access, nonstructural wood, and moisture

Category	N	Infested Houses Number	%
Political Boundary			
Jacksonville Beach/ St. Johns County	1288	169	13.12
Flagler County	98	3	3.06
Structural Wood			
Slab-on-grade wood frame or slab-on-grade concrete block frame with exterior paneling	975	151	15.49
Not slab-on-grade wood frame or slab-on-grade concrete block frame with exterior paneling	403	19	4.71
Pre-construction treatment			
Repellent vertical soil treatments	687	109	15.87
Non-repellent vertical soil treatment	699	63	9.01
Termite Access			
No inspection gap around the foundation perimeter, trees, shrubs, stumps < 60.96 cm (2 ft) from foundation, irrigation or lighting lines < 60.96 cm from foundation	1221	159	13.02
None of the above	117	10	8.55
Non-Structural Wood			
Fence post, firewood, or mulch > 60.96 (2 ft) from foundation	1108	141	12.73
Fence post, firewood, or mulch < 60.96 (2 ft) from foundation	278	31	11.15
Moisture			
Air conditioner condensation drip line < 60.96 cm (2 ft) from foundation, gutter downspout < 60.96 cm from foundation, sprinkler heads < 60.96 cm from foundation, or partial or no gutters	1253	157	12.53
None of the above	84	8	9.52

Table 5-3. The subterranean termite risk assessment system including all variables (N=1331)

Parameter	Hazard Ratio [1]	P	Probability [2]	Scaled Probability [3]
Political Boundary. House located in either St. Johns County or Jacksonville Beach, as opposed to Flagler County	1.524	0.0441	0.60	33.13
Structural Wood. Slab-on-grade wood frame or concrete block frame with exterior paneling	0.739	0.0072	0.42	23.31
Pre-construction Treatment. Repellent pre-construction treatment	0.662	0.0008	0.40	21.85
Termite Access. No inspection gap, trees or shrubs within two feet of foundation, irrigation or lighting lines within two feet of foundation	0.655	0.0823	0.40	21.71
Sum			1.82	100.00

1. Generated using Proc Phreg (SAS Institute 2000).
2. Parameter probability = hazard ratio/(hazard ratio + 1) (Allison 1991).
3. Probabilities scaled to 100 points [(100*probability)/probability sum].

Table 5-4. Comparison of the proportion of houses scoring above the median, 78.15, from the 90% model data set and the validation data set (10.52% of entire set). Scores of validation data set were determined by conditional logistic regression of 90% of the entire data set

	Model Data Set (90%)		Validation Data Set (10%)				
	n	Mean ± SEM	n	Mean ± SEM	t-value	df	*P*
Infested	149	87.80 ± 1.14	18	85.94 ± 3.58	-0.53	165	0.5972
Not Infested	1042	77.02 ± 0.61	122	74.47 ± 1.96	-1.35	1162	0.1768
Total	1191		140				

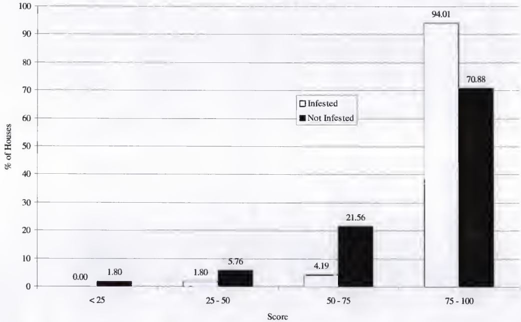

Figure 5-1. Percentage of infested and not infested houses scoring within quartiles.

CHAPTER 6
SUMMARY AND CONCLUSIONS

This research determined the effects of construction practices and home maintenance on subterranean termite infestations. Laboratory bioassays using soil collected from Alachua County comprised the first portion of the research. The second portion utilized a homeowner survey to determine if the Termite Protection Ordinance of St. Johns County influenced subterranean termite infestation rates, construction features, and house maintenance characteristics. County and PMP treatment records allowed me to evaluate the effects of time, political boundary, preconstruction chemical soil treatment, and factors relating to soil moisture, cellulose around the foundation, and hidden subterranean termite access on structural infestation rates of the homes.

Minimum pH levels of soil adjacent to new Gainesville, Florida structures covered by either stucco or siding corresponded with the pH range, 4.5 through 6.5, reported in the County's soil survey (Thomas et al. 1985). However, pH of soil adjacent to new brick on Gainesville, Florida houses was alkaline. Since alkaline pH does not normally occur in the Alachua County area, the high pH of soil adjacent to new brick veneer work was likely due to cement powder becoming mixed with the soil. Areas of varying levels of cement contamination probably result from the construction process. This scrap cement, in the presence of soil moisture, raises soil alkalinity and leads to subsequent hydrolysis of applied termiticides.

The effect of elevated soil pH from masonry cement on residual soil termiticide performance was investigated in the laboratory using subterranean termite mortality as an indicator. Mortality comparisons between 5 day, 5 month, and 10 month bioassays indicated that alkaline soil pH significantly decreased residual efficacy of imidacloprid and fipronil at 0.1x label rates, and chlorpyrifos, bifenthrin, and permethrin at 0.01x the label rates. Cypermethrin was not affected by soil pH.

Residual activity of low initial soil concentrations for five out of six of the termiticides tested were affected by alkaline pH. All. Although affected concentrations were 0.1x to 0.01x the manufacturers' recommended application rates, they are important because areas of low termiticide concentration result from non-uniform distribution of termiticide in the soil. These low field concentrations may occur in conjunction with cement added to the soil in the termiticide treatment area. The presence of moisture causes hydrolysis of the cement thereby freeing enough hydroxyl ions to increase soil pH, and consequently cause termiticide breakdown. An additional concern is that disruption or movement of the soil in the termiticide treatment area during the construction process may also cause low concentration of chemical to occur. According to this laboratory study, termite mortality caused by low concentrations of chlorpyrifos, imidacloprid, fipronil, bifenthrin, and permethrin declined in soil made alkaline by the addition of portland cement.

For the second portion of this research, homeowner responses to a mailed survey allowed classification of single-family houses built between 1994 and 1998 in Jacksonville Beach, St. Johns County, and Flagler County according to their subterranean termite infestation history, construction type, and maintenance characteristics. Pest

control companies and county records provided preconstruction soil chemical treatment information. Infestation rates were: 17.60% from Jacksonville Beach, 15.85% from St. Johns County, and 2.70% from Flagler County. The different infestation rates among the three areas were likely due to differences in construction types. Overall, subterranean termite infestations were strongly associated with older houses constructed from wood frames.

Additionally, sprinklers, gutter downspouts, air conditioner condensation driplines, and trees/shrubs/stumps near the foundation were also significantly associated with infestation rates. However, conditional logistic regression of all covariates together revealed the relationships among factors in order of their influence on infestation likelihood were: political boundary > occurrence of structural wood > repellent preconstruction termiticide treatment > termite access to structure via foraging guidelines and lack of foundation perimeter inspection space.

The effect of the St. Johns County Building Code on infestation rates of houses built after addition of a Termite Protection Ordinance was also evaluated. Poor implementation of the Ordinance made it impossible to fully evaluate its impact. The new Code, however, successfully increased consumer awareness regarding original preconstruction soil treatment pest control company.

APPENDIX A
SERIAL DILUTION DERIVATIONS

Table A-1. Amount of active ingredient (AI) in each of the formulated termiticides tested

Termiticide	%AI	lb AI/gal
Dursban TC	44.0	4
Premise 2	21.4	2
Termidor SC	9.1	0.9
Talstar	7.9	0.67
Prelude	25.6	2
Demon TC	25.3	2

3.3 mL solution added to 33 g soil for 10% moisture. All stock solutions were prepared so as to make soil concentration 10x label rate.

10,000 ppm Dursban TC (DTC)

Soil concentration: 10,000 ppm = 1% = $\frac{0.01 \text{ g AI}}{\text{g soil}}$

Stock dilution concentration: 20.9 mL DTC per 100 mL solution total volume

Check

$$\frac{20.9 \text{ mL DTC}}{100 \text{ mL solution}} * \frac{4 \text{ lb AI}}{\text{gal DTC}} * \frac{453.59 \text{ g}}{\text{lb}} * \frac{1 \text{ gal DTC}}{3785.33 \text{ mL DTC}} * \frac{3.3 \text{ mL solution}}{33 \text{ g soil}} = \frac{0.01 \text{ g AI}}{\text{g soil}}$$

= 1% = 10,000 ppm

500 ppm Premise 2 (P2)

Soil concentration: 500 ppm = 0.05% = $\frac{0.0005 \text{ g AI}}{\text{g soil}}$

Stock dilution concentration: 2.1 mL P2 per 100 mL solution total volume

Check

$$\frac{2.1 \text{ mL P2}}{100 \text{ mL solution}} * \frac{2 \text{ lb AI}}{\text{gal P2}} * \frac{453.59 \text{ g}}{\text{lb}} * \frac{1 \text{ gal P2}}{3785.33 \text{ mL P2}} * \frac{3.3 \text{ mL solution}}{33 \text{ g soil}} = \frac{0.0005 \text{ g AI}}{\text{g soil}}$$

= 0.05% = 500 ppm

600 ppm Termidor (T)

Soil concentration: 600 ppm = 0.06% = $\frac{0.0006 \text{ g AI}}{\text{g soil}}$

Stock dilution concentration: 5.6 mL T per 100 mL solution total volume

Check

$$\frac{5.6 \text{ mL T}}{100 \text{ mL solution}} * \frac{0.9 \text{ lb AI}}{\text{gal T}} * \frac{453.59 \text{ g}}{\text{lb}} * \frac{1 \text{ gal T}}{3785.33 \text{ mL T}} * \frac{3.3 \text{ mL solution}}{33 \text{ g soil}} = \frac{0.0006 \text{ g AI}}{\text{g soil}}$$

= 0.06% = 600 ppm

600 ppm Talstar (T)

Soil concentration: 600 ppm = 0.06% = $\frac{0.0006 \text{ g AI}}{\text{g soil}}$

Stock dilution concentration: 7.5 mL T per 100 mL solution total volume

Check

$$\frac{7.5 \text{ mL T}}{100 \text{ mL solution}} * \frac{0.67 \text{ lb AI}}{\text{gal T}} * \frac{453.59 \text{ g}}{\text{lb}} * \frac{1 \text{ gal T}}{3785.33 \text{ mL T}} * \frac{3.3 \text{ mL solution}}{33 \text{ g soil}} = \frac{0.0006 \text{ g AI}}{\text{g soil}}$$

= 0.06% = 600 ppm

10,000 ppm Prelude (P)

Soil concentration: 10,000 ppm = 1% = $\frac{0.01 \text{ g AI}}{\text{g soil}}$

Stock dilution concentration: 42 mL P per 100 mL solution total volume

Check

$$\frac{42 \text{ mL P}}{100 \text{ mL solution}} * \frac{2 \text{ lb AI}}{\text{gal P}} * \frac{453.59 \text{ g}}{\text{lb}} * \frac{1 \text{ gal P}}{3785.33 \text{ mL P}} * \frac{3.3 \text{ mL solution}}{33 \text{ g soil}} = \frac{0.01 \text{ g AI}}{\text{g soil}}$$

= 1% = 10,000 ppm

5,000 ppm Demon TC (DTC)

Soil concentration: 5,000 ppm = 0.5% = $\frac{0.005 \text{ g AI}}{\text{g soil}}$

Stock dilution concentration: 21 mL DTC per 100 mL solution total volume

Check

$$\frac{21 \text{ mL DTC}}{100 \text{ mL solution}} * \frac{2 \text{ lb AI}}{\text{gal DTC}} * \frac{453.59 \text{ g}}{\text{lb}} * \frac{1 \text{ gal DTC}}{3785.33 \text{ mL DTC}} * \frac{3.3 \text{ mL solution}}{33 \text{ g soil}} = \frac{0.005 \text{ g AI}}{\text{g soil}}$$

= 0.5% = 5,000 ppm

APPENDIX B
LABEL RATE CALCULATION

Depth = 1 ft (30.48 cm) Width = ½ ft (15.24 cm) Length = 10 ft (304.8 cm)

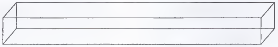

Fig. B-1. Standard trench. Volume of trench = 141,584.233 cm^3. If 100 cm^2 soil weighs 112.76 g, then there is 159,650.3811 g soil in a standard trench. Trench treatment = 4 gal/10 lin ft/ft depth (Adapted from Powell 2000).

Equation B-1 shows Dursban TC label rate soil concentration.

$$\frac{4\ \text{gal}}{159{,}650.3811\ \text{g soil in trench}} * \frac{3785.33\ \text{mL}}{1\ \text{gal}} * \frac{1\ \text{g AI}}{100\ \text{mL}} = \frac{0.001\ \text{g AI}}{100\ \text{g soil}} = 0.1\% = 1{,}000\ \text{ppm} \quad \text{(B-1)}$$

Equation B-2 shows Premise 2 label rate soil concentration.

$$\frac{4\ \text{gal}}{159{,}650.3811\ \text{g soil in trench}} * \frac{3785.33\ \text{mL}}{1\ \text{gal}} * \frac{0.05\ \text{g AI}}{100\ \text{mL}} = \frac{4.72 \times 10^{-5}\ \text{g AI}}{100\ \text{g soil}} = 0.005\% = 50\ \text{ppm} \quad \text{(B-2)}$$

Equation B-3 shows Termidor SC label rate soil concentration.

$$\frac{4\ \text{gal}}{159{,}650.3811\ \text{g soil in trench}} * \frac{3785.33\ \text{mL}}{1\ \text{gal}} * \frac{0.06\ \text{g AI}}{100\ \text{mL}} = \frac{5.69 \times 10^{-5}\ \text{g AI}}{100\ \text{g soil}} = 0.006\% = 60\ \text{ppm} \quad \text{(B-3)}$$

Equation B-4 shows Talstar label rate soil concentration.

$$\frac{4\ \text{gal}}{159{,}650.3811\ \text{g soil in trench}} * \frac{3785.33\ \text{mL}}{1\ \text{gal}} * \frac{0.06\ \text{g AI}}{100\ \text{mL}} = \frac{5.69 \times 10^{-5}\ \text{g AI}}{100\ \text{g soil}} = 0.006\% = 60\ \text{ppm} \quad \text{(B-4)}$$

Equation B-5 shows Demon TC label rate soil concentration.

$$\frac{4\ \text{gal}}{159{,}650.3811\ \text{g soil in trench}} * \frac{3785.33\ \text{mL}}{1\ \text{gal}} * \frac{0.5\ \text{g AI}}{100\ \text{mL}} = \frac{4.7 \times 10^{-4}\ \text{g AI}}{100\ \text{g soil}} = 0.05\% = 500\ \text{ppm} \quad \text{(B-5)}$$

Equation B-6 shows Prelude label rate soil concentration.

$$\frac{4\ \text{gal}}{159{,}650.3811\ \text{g soil in trench}} * \frac{3785.33\ \text{mL}}{1\ \text{gal}} * \frac{1\ \text{g AI}}{100\ \text{mL}} = \frac{0.001\ \text{g AI}}{100\ \text{g soil}} = 0.1\% = 1{,}000\ \text{ppm} \quad \text{(B-6)}$$

APPENDIX C
ANOVA TABLE FOR A FACTORIAL EXPERIMENT TO EVALUATE THE EFFECT OF TIME ON CONTROL SOIL pH

Table C-1. Starting pH 6.01 ± 0.02

Source	df	SS	MS	F	*P*
Time	2	0.415	0.208	5.33	0.0467
Error	6	0.234	0.039		

Table C-2. Starting pH 7.02 ± 0.01

Source	df	SS	MS	F	*P*
Time	2	0.616	0.308	7.97	0.0204
Error	6	0.232	0.039		

Table C-3. Starting pH 8.02 ± 0.01

Source	df	SS	MS	F	*P*
Time	2	3.561	1.780	48.35	0.0002
Error	6	0.221	0.037		

Table C-4. Starting pH 9.07 ± 0.01

Source	df	SS	MS	F	*P*
Time	2	8.286	4.143	436.31	< 0.0001
Error	6	0.057	0.009		

APPENDIX D
THREE-WAY ANOVA OF THE EFFECTS OF CONCENTRATION, PH, AND TIME ON THE MORTALITY OF TERMITES CONFINED ON SOIL TREATED WITH TERMITICIDES

Table D-1. Three-way ANOVA of the effects on concentration, pH, and time on the mortality of termites confined on soil treated with termiticides.

Treatment	Source	df	MS	*F*	*P*
Bifenthrin (Talstar)	Conc (C)	4	17.1671	5257.70	< 0.0001
	pH	3	0.0982	30.06	< 0.0001
	Time (T)	2	0.7836	239.99	< 0.0001
	pH X T	6	0.0270	8.28	< 0.0001
	C X pH	12	0.0982	30.06	< 0.0001
	C X T	8	0.7836	239.99	< 0.0001
	C X pH X T	24	0.0270	8.28	< 0.0001
	Error	120	0.0033		
Permethrin (Prelude)					
	Conc (C)	4	16.6649	28273.80	< 0.0001
	pH	3	0.0129	21.92	< 0.0001
	Time (T)	2	0.9106	1544.96	< 0.0001
	pH X T	6	0.0129	21.92	< 0.0001
	C X pH	12	0.0129	21.92	< 0.0001
	C X T	8	0.9106	1544.96	< 0.0001
	C X pH X T	24	0.0129	21.92	< 0.0001
Chlorpyrifos (Dursban TC)	Error	120	0.0006		
	Conc (C)	4	16.7646	4622.34	< 0.0001
	pH	3	0.1407	38.79	< 0.0001
	Time (T)	2	0.1339	36.93	< 0.0001
	pH X T	6	0.0426	11.74	< 0.0001
	C X pH	12	0.1407	38.79	< 0.0001
	C X T	8	0.1339	36.93	< 0.0001
	C X pH X T	24	0.0426	11.74	< 0.0001
	Error	120	0.0036		

Percentage termite mortality was arcsine square-root transformed before analysis. Control mortality was 0%.

Table D-2. Three-way ANOVA of the effects on concentration, pH, and time on the mortality of termites confined on soil treated with termiticides.

Treatment	Source	df	MS	F	*P*
Fipronil (Termidor SC)	Conc (C)	4	15.3920	6293.53	< 0.0001
	pH	3	0.4125	168.67	< 0.0001
	Time (T)	2	0.4091	167.29	< 0.0001
	pH X T	6	0.1636	66.88	< 0.0001
	C X pH	12	0.1569	64.15	< 0.0001
	C X T	8	0.2994	122.43	< 0.0001
	C X pH X T	24	0.0676	27.63	< 0.0001
	Error	120	0.0024		
Imidacloprid (Premise 2)					
	Conc (C)	4	16.0455	7470.73	< 0.0001
	pH	3	0.0590	27.45	< 0.0001
	Time (T)	2	2.6505	1234.07	< 0.0001
	pH X T	6	0.0274	12.76	< 0.0001
	C X pH	12	0.0235	10.94	< 0.0001
	C X T	8	1.1318	526.98	< 0.0001
	C X pH X T	24	0.0158	7.33	< 0.0001
	Error	120	0.0021		

Percentage termite mortality was arcsine square-root transformed before analysis. Control mortality was 0%.

APPENDIX E

MORTALITIES OF *R. FLAVIPES* CONFINED ON SOIL OF DIFFERENT PH LEVELS (6, 7, 8 & 9), TREATED WITH TERMITICIDES, AND AGED EITHER 5 OR 10 MONTHS

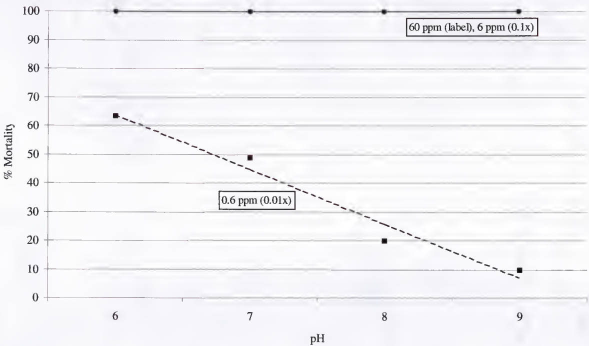

Figure E-1. Bifenthrin (Talstar) at 5 months.

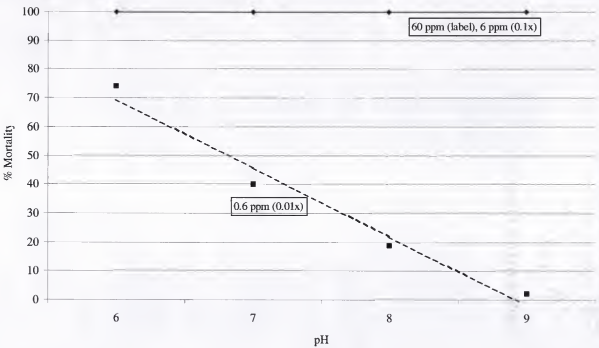

Figure E-2. Bifenthrin (Talstar) at 10 months.

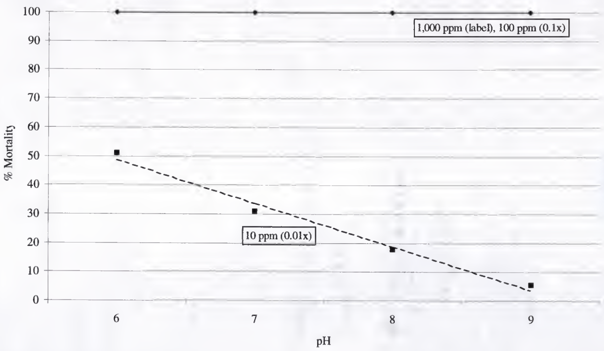

Figure E-3. Permethrin (Prelude) at 10 months.

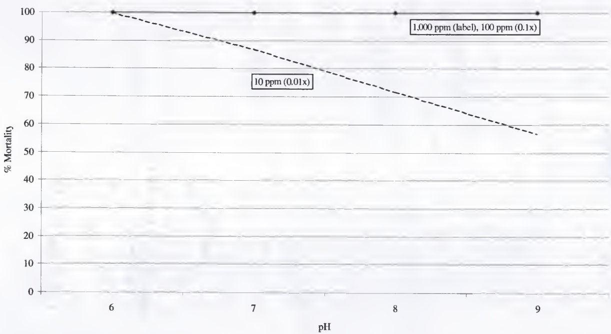

Figure E-4. Chlorpyrifos (Dursban TC) at 5 months.

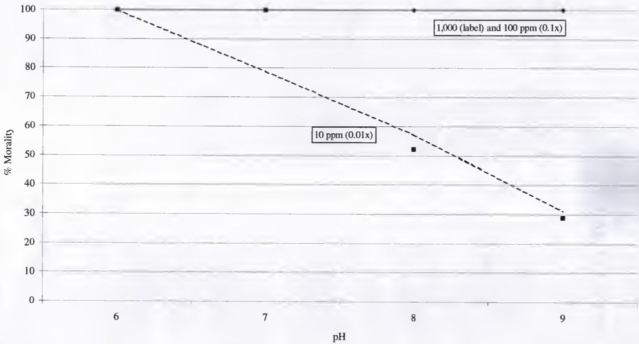

Figure E-5. Chlorpyrifos (Dursban TC) at 10 months.

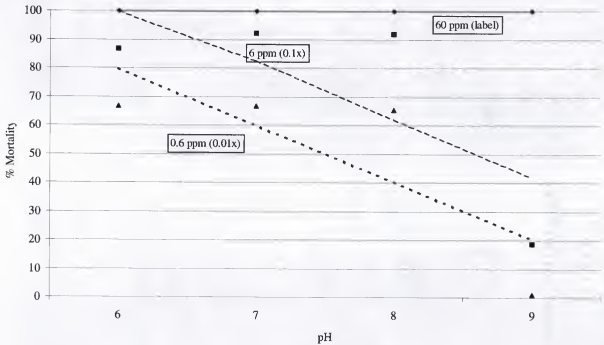

Figure E-6. Fipronil (Termidor SC) at 5 months.

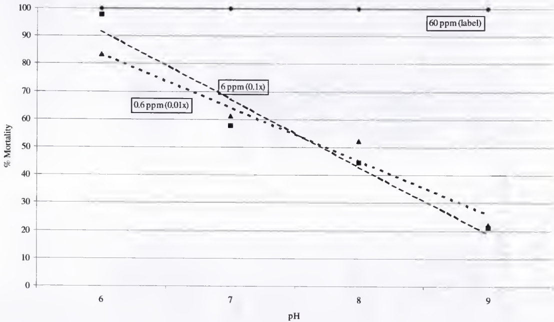

Figure E-7. Fipronil (Termidor SC) at 10 months.

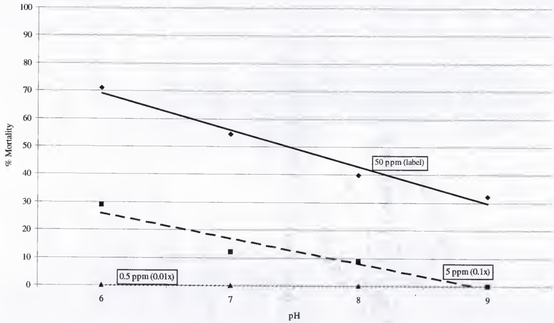

Figure E-8. Imidacloprid (Premise 2) at 5 months.

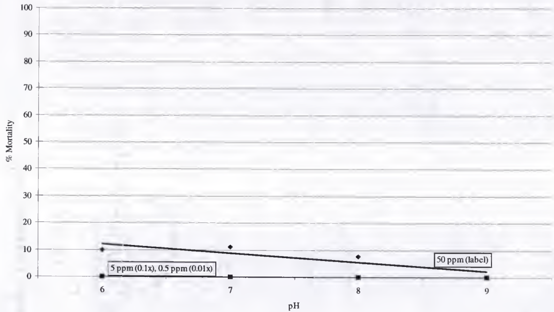

Figure E-9. Imidacloprid (Premise 2) at 10 months.

APPENDIX F

ANOVA TABLE FOR A FACTORIAL EXPERIMENT TO EVALUATE THE EFFECT OF EITHER SOIL TERMITICIDE CONCENTRATION ON TERMITE MORTALITY OR SOIL pH ON SPECIFIC CONCENTRATIONS OF SOIL TERMITICIDES AS INDICATED BY TERMITE MORTALITY

Table F-1. ANOVA table for Bifenthrin (Talstar)

5 Months, 0.6 ppm					
Source	df	SS	MS	F	P
pH	3	0.8112	0.2704	12.24	0.0023
Error	8	0.1767	0.0221		

10 Months, 0.6 ppm					
Source	df	SS	MS	F	P
pH	3	1.4720	0.4907	18.25	0.0006
Error	8	0.2151	0.0269		

Table F-2. ANOVA table for Permethrin (Prelude)

10 Months, 10 ppm					
Source	df	SS	MS	F	P
pH	3	0.5815	0.1938	21.92	0.0003
Error	8	0.0707	0.0088		

Table F-3. ANOVA table for Chlorpyrifos (Dursban TC).

5 Months, 10 ppm					
Source	df	SS	MS	F	P
pH	3	0.9908	0.3203	5.94	0.0197
Error	8	0.4313	0.0539		

10 Months, 10 ppm					
Source	df	SS	MS	F	P
pH	3	2.4267	0.8089	1657.17	<0.0001
Error	8	0.0039	0.0005		

Table F-4. ANOVA table for Fipronil (Termidor SC)

5 Days

Source	df	SS	MS	F	P
Concentration	4	22.980	5.745	10262.5	<0.0001
Error	55	0.031	0.001		

5 Months, 0.6 ppm

Source	df	SS	MS	F	P
pH	3	1.5504	0.5168	60.56	<0.0001
Error	8	0.0683	0.0085		

10 Months, 6 ppm

Source	df	SS	MS	F	P
pH	3	1.6498	0.5499	58.68	<0.0001
Error	8	0.0750	0.0094		

5 Months, 0.6 ppm

Source	df	SS	MS	F	P
pH	3	1.7959	0.5986	225.85	<0.0001
Error	8	0.0212	0.0027		

10 Months, 6 ppm

Source	df	SS	MS	F	P
pH	3	0.7148	0.2382	17.20	0.0008
Error	8	0.1108	0.0139		

Table F-5. ANOVA table for Imidacloprid (Premise 2)

5 Days

Source	df	SS	MS	F	P
Concentration	4	29.626	7.406	43593.5	<0.0001
Error	55	0.009	0.001		

5 Months, 5 ppm

Source	df	SS	MS	F	P
pH	3	0.4837	0.1612	21.83	0.0003
Error	8	0.0591	0.0074		

5 Months, 50 ppm

Source	df	SS	MS	F	P
pH	3	0.2962	0.0987	7.30	0.0112
Error	8	0.1082	0.0135		

10 Months, 50 ppm (1 day)

Source	df	SS	MS	F	P
pH	3	0.2190	0.0730	6.98	0.0127
Error	8	0.0836	0.0105		

10 Months, 5 ppm (7 days)

Source	df	SS	MS	F	P
pH	3	0.0787	0.0262	7.00	0.0126
Error	8	0.0300	0.0037		

APPENDIX G
COVER LETTER INCLUDED WITH SURVEY MAILED TO HOMEOWNERS

Dear Homeowner:

I am a graduate student at the University of Florida. As part of my dissertation project, I am conducting a Termite Infestation and Construction Survey, the purpose of which is to determine 1) if new construction practices, as required by St. Johns County, have reduced infestation rates, 2) the economic impact of subterranean termite infestations on homeowners, and 3) to recommend construction and maintenance practices that reduce risk of subterranean termite infestations. If you return this survey, you will receive these recommendations in approximately 18 months.

I am asking you to participate in this survey by answering and returning the enclosed form because your residence has been identified as being built during the past four years. I will be surveying properties built within the past four years in Flagler, St. Johns, and Duval Counties. Only I will have access to the returned surveys. Your identity and property information will remain anonymous to the extent provided by law.

There are no anticipated risks, compensation, or other direct benefits to you as a participant in this interview. You are free not to participate in this survey, although participation is strongly encouraged.

If you have any questions about this research protocol, please contact me at (352) 392-1901 ext.119 or my faculty advisor, Dr. Philip Koehler, at (352) 392-2484. Questions or concerns about your rights as a research participant may be directed to the

UFIRB Office, Protocol #1999.878, University of Florida, Box 112250, Gainesville, Florida 32611; ph (352) 392-0433.

Please answer and return the survey in the enclosed envelope. By returning this survey, you give me permission to report your responses anonymously in the documented results of this study.

Dina L. Richman

APPENDIX H
CHEMICALS USED FOR PRECONSTRUCTION TREATMENTS IN NORTHEAST FLORIDA

Table H-1. Chemicals used for preconstruction treatments in northeast Florida

Company Name	Chemical and Concentration
Ancient City	Demon 0.5% (cypermethrin) or Premise 75 0.05% (imidacloprid)
B & B	Prevail 0.25% (cypermethrin) or Biflex 0.06% (bifenthrin)
Baker	Dursban 0.75% (chlorpyrifos) or Premise 75 0.05% (imidacloprid)
Bug Guard	Demon 0.5% (cypermethrin)
Bug Out	Demon 0.5% (cypermethrin)
Centex HTS	Dursban 0.75% (chlorpyrifos)
Certified	Demon 0.5% (cypermethrin)
Cody	Demon 0.25% (cypermethrin)
Enviro	Demon 0.25% (cypermethrin)
Florida Pest Control	Dursban 0.5, 0.75, or 1% (chlorpyrifos)
Massey	Dursban 0.75% (chlorpyrifos) or Prevail 0.25% (cypermethrin) or Tribute 0.5% (fenvalerate)
McCalls	Demon 0.25% (cypermethrin) or Termidor 0.06% (fipronil)
Naders	Dursban 0.75% (chlorpyrifos) or Prevail 0.25% (cypermethrin)
Orkin	Dragnet 0.5% (permethrin) or Prelude 0.5% (permethrin)
Peninsular	Dursban 1% (chlorpyrifos)
Pest Defense Systems	Dursban 0.75% (chlorpyrifos)
Pest Experts	Dursban 0.75% (chlorpyrifos)
Rivers	Dursban 0.75% (chlorpyrifos) or Prevail 0.25% (cypermethrin)

Table H-1. Continued

Company Name	Chemical and Concentration
St. Augustine Service	Demon 0.5% (cypermethrin) or Prevail 0.25% (cypermethrin)
Sears	Dragnet 0.5% (permethrin)
Smith Brothers	Premise 75 0.05% (imidacloprid)
Terminix	Dragnet 0.05% (permethrin) or Premise 75 0.05% (imidacloprid)
Tropical	Demon 1% (cypermethrin)
Turner	Prevail 0.25% (cypermethrin)
Zion	Demon 0.5% (cypermethrin)

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BIOGRAPHICAL SKETCH

Dina L. Richman was born in Brooklyn, New York, August 25, 1971 to Jack and Laura Richman. She attended grade school in Staten Island, New York. When Dina was 8 years old, she moved with her parents and younger sister to Sunrise, Florida, where she completed grade, middle, and high school. She graduated from Piper High School in 1989. She received her B.S. in zoology from Florida Atlantic University in 1994. She then relocated to Gainesville, FL, for graduate school study and received her Master of Science degree in Entomology in 1997. Dina recently accepted an industry position with FMC Corp. in Philadelphia, PA, as a Product Development Associate in Urban Entomology.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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